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# ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J4-1001-06, -07, -11, AND -15)

C. E. Pillow

ARO, Inc.

September 1970



ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

# NOTICES

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## FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EP-J), under Program Element 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of Arnold Engineering Development Center (AEDC). Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on August 25, 28, September 17, and October 29, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF) under ARO Project No. RN1001. The manuscript was submitted for publication on June 19, 1970.

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This technical report has been reviewed and is approved.

Walter C. Knapp
Lt Colonel, USAF
AF Representative, ETF
Directorate of Test

Roy R. Croy, Jr.
Colonel, USAF
Director of Test

## ABSTRACT

Eleven firings of the Rocketdyne J-2S rocket engine were conducted in Rocket Development Test Cell (J-4) of the Engine Test Facility on August 25, 28, September 17, and October 29, 1969. These firings were accomplished at pressure altitudes ranging from 80,000 to 108,000 ft at engine start signal. The major objectives for these tests were to verify stable idle-mode operation, confirm that oxidizer injection temperatures were not excessive during transition from main-stage to post-main-stage idle-mode operation, evaluate main-stage performance, and determine the rate at which thrust chamber temperature increased during pre-main-stage idle mode. A full-face oxidizer flow injector configuration was utilized during this series of tests for the distribution of oxidizer during idle-mode operation. Brief durations (<20 sec) of stable idle-mode operation (chamber pressure oscillations <±1 psi) were achieved. Oxidizer injection temperatures exhibited only insignificant increases (<10°F) during transition to post-main-stage idle-mode operation. The maximum rate at which the thrust chamber temperature increased during idle-mode operation with high oxidizer (45-psia) and low fuel (27-psia) pump inlet conditions was 6°F/sec. Three firings which simulated orbital restart conditions were prematurely terminated during transition to main stage by the vibration safety cutoff system. Liquid fuel was present at the injector at dome prime when the excessive vibrations were first recorded.

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## NOMENCLATURE

| | |
|---|---|
| A | Area, sq in. |
| ASI | Augmented spark igniter |
| CCP | Customer connect panel |
| EBW | Exploding bridgewire |
| FM | Frequency modulation |
| MFV | Main fuel valve |
| MOV | Main oxidizer valve |
| O/F | Propellant mixture ratio, oxidizer to fuel, by weight |
| SPTS | Solid-propellant turbine starter |
| T/C | Thrust chamber |
| t-0 | Time at which helium control and idle-mode solenoids are energized; engine start |
| VSC | Vibration safety counts, indicators of engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range |

### SUBSCRIPTS

| | |
|---|---|
| f | Force |
| m | Mass |
| t | Throat |

# SECTION I
# INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress at AEDC since December 1968. Reported herein are the results of eleven firings conducted during test periods J4-1001-06,-07,-11 and -15. The major objectives for these tests were to verify stable idle-mode operation and transition from main-stage to idle-mode operation, to evaluate main-stage performance, and determine the rate at which the thrust chamber temperature increased during pre-main-stage idle mode.

The firings reported herein were accomplished in Rocket Development Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Engine Test Facility (ETF) at pressure altitudes ranging from 80,000 to 108,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start signal. Data collected to accomplish the test objectives are presented herein.

# SECTION II
# APPARATUS

## 2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lbf and mixture ratio of 2.5, or at main stage at any precalibrated thrust level between 230,000 and 265,000 lbf at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for these test periods are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

### 2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5, Refs. 2 and 3) features the following major components:

1. Thrust Chamber — The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat diameter of 12.192 in., a characteristic length ($L^*$) of 35.4, and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling is accomplished by the circulation of engine fuel flow

downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector – The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 sq in.. respectively. The porous material, forming the injector face, allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector. During idle-mode operation, oxidizer is supplied through a diffuser located in the top of the injector (Fig. 5c) which disperses the oxidizer to all portions of the injector face. During main-stage operation the main oxidizer valve is opened and supplies the major flow of oxidizer to the injector face.

3. Augmented Spark Igniter – The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump – The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lbf-thrust-rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump – The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lbf-thrust-rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve – The motor-driven propellant utilization valve is a sleeve-type valve mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main Oxidizer Valve – The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high-pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at the nominal 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve fully open to accelerate the engine to the main-stage operating level.

8. Main Fuel Valve – The main fuel valve is a pneumatically actuated, butterfly-type valve located in the fuel high-pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package – The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly – The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package – The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank – The helium tank has a volume of 4000 cu in. and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve – The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve – The idle-mode valve is a pneumatically operated, ball-type valve which supplies liquid oxygen to the idle-mode diffuser of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve – The hot gas tapoff valve is a pneumatically operated, butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter – The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

### 2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter, is 49 ft long, and has a maximum propellant capacity of 43,000 lbm of liquid hydrogen and 194,000 lbm of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low-pressure ducts (external to the tanks) interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting systems.

## 2.2 TEST CELL

Rocket Development Test Cell (J-4), Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engine and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) storage and delivery systems for coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid-oxygen and gaseous-helium for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consists of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous-nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown.

The test cell was also equipped with (1) a gaseous-nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous-nitrogen repressurization system for raising test cell pressure after engine cutoff to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid-nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

## 2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. Engine vibrations were measured by piezoelectric accelerometers. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and capacitance-type pressure transducer.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 50 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

### 2.4 CONTROLS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Figs. 7a and b.

## SECTION III
## PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished; engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer injector and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the solid-propellant turbine starters were installed, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for engine main-stage operation. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Table V presents the engine purge and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

# SECTION IV
# RESULTS AND DISCUSSION

## 4.1 GENERAL

Eleven firings of the Rocketdyne J-2S rocket engine (S/N J-112-1F during tests J4-1001-06, -07, and -11 and S/N J-112-1H during test J4-1001-15) were accomplished. These test periods were conducted on August 25, 28, September 17, and October 29, 1969, respectively, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF). Pressure altitudes at engine start signal ranged from 80,000 to 108,000 ft.

Each of the firings utilized a solid-propellant turbine starter to supply the necessary energy to transition from idle-mode to main-stage operation. Previous test periods which used solid-propellant turbine starters are presented in Refs. 5 and 6.

The injector assembly has been modified several times since the initiation of testing of the J-2S engine at AEDC. The first injector assembly utilized was an inner four row configuration injector (Fig. 8). Low idle-mode performance and engine damage resulting from detonations in the thrust chamber necessitated the change to the row ten oxidizer injection configuration, Fig. 8. This design was to improve propellant mixing and combustion efficiency. The increase in combustion efficiency was relatively insignificant. Therefore, simulations of the full face oxidizer flow configuration injector were conducted using an inner four row configuration injector with the main oxidizer valve open to its first-stage position during idle-mode operation. Results of those simulations demonstrated improved performance and feasibility of the proposed configuration. The subsequent configuration (full-face oxidizer flow) reported herein allowed oxidizer to be dispersed across the entire injector face (Fig. 8) during idle mode with the main oxidizer valve closed. Firing J4-1001-06A was the first firing to utilize the full-face oxidizer flow configuration injector.

In addition to low performance during idle-mode operation, oxidizer injection temperatures were excessively high (up to 1500°F during transition to post-main-stage idle-mode operation. However, with the full-face oxidizer flow injector, increases in oxidizer injection temperature were insignificant (<10°F) during transition to post-main-stage idle-mode operation.

A summary of significant test variables and results is presented in the matrix on page 8. Specific test objectives and results are presented in subsequent sections. The data presented were obtained using the digital data acquisition system, unless indicated otherwise.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Engine start conditions for the propellant pump inlets and the helium tank are shown in Fig. 9. The results of the firings reported herein are presented in Figs. 10 through 53.

## 4.2 TEST RESULTS

### 4.2.1 Firing J4-1001-06A

The objectives for this firing were to (1) verify stable post-main-stage idle-mode operation, (2) confirm that oxidizer injection temperatures were not excessive during transition to post-main-stage idle mode, (3) and evaluate main-stage performance. The S-IVB battleship stage prevalves were opened approximately 60 min before engine start signal to precondition the propellant feed systems.

Post-main-stage idle-mode operation was accomplished; however, stabilized engine operation was not attained. Chamber pressure oscillations were observed from 4.3 sec after main-stage cutoff signal until engine cutoff signal. Pressure oscillations of up to ±9 psi were recorded in the fuel feed system during this time period. Corresponding fuel injection temperature increases of up to 100°F were also observed. The thrust chamber external skin temperatures, TTCT-T1 and E1, were increasing from 1.8 sec after main-stage cutoff signal until engine cutoff signal. The maximum throat temperature was -190°F at engine cutoff signal. Thrust chamber heat transfer rates may have been affected by increasing engine ambient pressure and temperature during post-main-stage idle-mode operation (Figs. 10 and 14). The maximum test cell pressure and temperature of 0.36 psia and 245°F respectively, were recorded 6.7 sec after main-stage cutoff signal.

Excessive oxidizer injection temperatures were not observed during transition to post-main-stage idle mode. There was a slight increase (<25°F) indicated in the oxidizer idle-mode supply line temperature. Previous tests, Ref. 7, using the inner four row injector configuration, experienced transient oxidizer injector temperatures as high as 1500°F during transition from main-stage to post-main-stage idle mode.

| Firing J4-1001- | 06A | 06B | 07A | 07B | 07C | 11A | 11B | 11C | 15A | 15B | 15C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel pump inlet pressure at t-0, psia | 33.0 | 33.3 | 33.2 | 33.4 | 41.8 | 41.1 | 27.9 | 39.7 | 29.9 | 30.1 | 32.4 |
| Oxidizer pump inlet pressure at t-0, psia | 39.6 | 39.3 | 39.2 | 46.0 | 39.3 | 39.7 | 40.3 | 31.7 | 39.2 | 44.7 | 32.5 |
| Main oxidizer valve First-Stage gate angle, deg | 11.5 | 11.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 11.7 | 11.7 | 11.7 |
| Oxidizer idle-mode line orifice diameter, in. | 0.848 | 0.848 | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 | 0.977 | 0.911 | 0.911 | 0.911 |
| Fuel bypass orifice diameter, in. | 1.750 | 1.750 | 1.750 | 1.750 | 1.750 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 |
| Tapoff valve open angle, deg | 58 **(1.321) | 58 (1.321) | 64 (1.260) | 64 (1.260) | 64 (1.260) | 58 (1.321) | 58 (1.321) | 58 (1.321) | 58 (1.321) | 58 (1.321) | 58 (1.321) |
| Duration of VSC, before engine cutoff signal, msec* | None | 315 | None | 1 | None | 345 | None | 475 | None | None | 270 |
| Premature cutoff | No | Yes | No | No | No | Yes | No | Yes | No | No | Yes |
| Oxidizer pump bearing cavity temperature at t-0 -5, °F | -288 | -116 | -288 | -84 | -278 | 96 | -276 | -128 | -289 | -292 | -63 |
| Fuel pump balance piston cavity temperature at t-0 -5, °F | -398 | -120 | -171 | -80 | -411 | 92 | -406 | -119 | -200 | -354 | -76 |

* Data reduced from oscillograph
** Tapoff valve mechanical stop length, in.

Improper engine orificing resulted in a mixture ratio of approximately 4.6 during main-stage operation with the propellant utilization valve in the null position (mixture ratio nominally 5.0). Main-stage performance data were calculated as shown in Appendix IV. Stabilized chamber pressure was attained by t-0 + 7 sec. Data between t-0 + 7.5 and t-0 + 8.5 sec were averaged, and performance data were calculated using these averages. The characteristic velocity, engine thrust, and specific impulse were approximately 7800 ft/sec, 230,000 lbf, and 434 lbf-sec/lbm, respectively.

### 4.2.2 Firing J4-1001-06B

The objectives for this firing were to (1) verify stable idle-mode operation, (2) confirm that oxidizer injection temperatures were not excessive during transition to post-main-stage idle mode and (3) evaluate main-stage performance. This firing was conducted at thermal conditions expected for an orbital restart mission. The oxidizer pump bearing coolant temperature (TOPBC) and the fuel pump balance piston sump temperature (TFPBS) were used as indicators of propellant turbomachinery thermal conditions. To achieve the required conditions, propellants were not admitted to the engine until 5 sec before engine start signal.

Stabilized idle-mode operation was attained 36 sec after engine start signal. Chamber pressure oscillations remained less than ±1 psi (18 to 20 psia) until 49 sec after engine start signal. Before 36 sec and after 49 sec, chamber pressure oscillations were greater than ±1 psi. Superheated oxidizer was present at the engine flowmeter during idle-mode operation. This prevented determination of oxidizer flow rate and calculation of idle-mode performance data.

A premature engine cutoff was initiated 1.5 sec after main-stage start signal by the vibration safety cutoff system. Liquid fuel conditions existed at the fuel injector during oxidizer dome prime (chamber pressure = 100 psia) when the excessive vibrations were first recorded.

### 4.2.3 Firing J4-1001-07A

The objectives for this firing were to (1) verify stable idle-mode operation, (2) confirm that oxidizer injection temperatures were not excessive during transition to post-main-stage idle-mode operation, and (3) evaluate main-stage performance. The stage prevalves were opened approximately 60 min before engine start signal to precondition the propellant feed systems.

Stabilized idle-mode operation was attained 20 sec after engine start signal. Chamber pressure oscillations remained less than ±1 psi (29 to 31 psia) until 39 sec after engine start signal. Before 20 sec and after 39 sec, chamber pressure oscillations were approximately ±2 psi. Unsteady fuel flow during idle mode prevented the evaluation of engine performance.

Stabilized post-main-stage idle-mode operation was not attained. Chamber pressure oscillations with amplitudes up to ±7 psi at a frequency of 1 Hz were observed for the duration of post-main-stage idle-mode operation. Pressure oscillations in the fuel system ranged up to ±9 psi in phase with the chamber pressure oscillations. Corresponding fuel injection temperature increases of up to 100°F were also observed. The thrust chamber external skin temperatures were increasing from 2 sec after main-stage cutoff signal until engine cutoff signal. The maximum throat temperature was -180°F at engine cutoff signal. Thrust chamber heat transfer rates may have been affected by the continuously increasing engine ambient pressure and temperature. The maximum test cell pressure and temperature were 0.55 psia and 240°F, respectively, recorded at engine cutoff signal. Unsteady fuel flow prevented idle-mode performance evaluation.

Excessive oxidizer injection temperatures were not observed during the transition to post-main-stage idle mode. Only a slight (<5°F) increase was recorded.

Comparison of fuel flow and the corresponding pressure drop across the fuel injector with previous main-stage firings revealed that the indicated pressure loss was abnormally low for the measured flow rate. Calculation of main-stage performance data resulted in an abnormally high specific impulse and characteristic velocity. This indicated a probable error in measured combustion chamber pressure. The error appears to be on the order of +7 percent and is suspected to be associated with icing of the chamber pressure measurement tap. If the chamber pressure tap iced over completely, the chamber pressure transducer would sense fuel injection pressure because of the purge line interconnect between the fuel injector and the chamber pressure measurement line (see Fig. III-1i). Engine mixture ratio was 4.8 with the propellant utilization valve in the null position.

### 4.2.4 Firing J4-1001-07B

The objectives for this firing were to (1) verify stable idle-mode operation, (2) confirm that oxidizer injection temperatures were not excessive during transition to post-main-stage idle mode, and (3) evaluate main-stage performance. This firing was conducted at thermal conditions expected for an orbital restart mission. The oxidizer pump bearing coolant temperature (TOPBC) and the fuel pump balance piston sump temperature (TFPBS) were used as indicators of propellant turbomachinery thermal conditions. To achieve the required conditions, propellants were not admitted to the engine until 5 sec before engine start signal.

Stabilized idle-mode operation was attained 40 sec after engine start signal. The chamber pressure was gradually increasing for the initial 40 sec. Oscillations with amplitudes greater than ±2 psi were observed during portions of this time period. After the initial 40 sec, chamber pressure was steadily increasing with oscillations of less than ±1 psi. Superheated propellants were present at the engine flowmeters during idle-mode operation. This prevented determination of propellant flow rates and subsequent calculation of idle-mode performance data.

Stabilized post-main-stage idle-mode operation was not achieved. Oscillations in chamber pressure with amplitudes up to ±4 psi were observed for the duration of post-main-stage idle-mode operation. Oscillations in the fuel system pressures ranged in amplitude up to ±8 psi and in phase with the chamber pressure oscillations. Corresponding fuel injection temperature increases of up to 200°F were also observed. The thrust chamber throat external skin temperature was increasing from 1 sec after main-stage cutoff signal until engine cutoff signal. The maximum throat temperature was -138°F at engine cutoff signal. Thrust chamber heat transfer rates may have been affected by abnormally high transient engine ambient pressure and temperature. A maximum pressure of 1.31 psia and 570°F were recorded approximately 3.5 sec after main-stage cutoff signal. Unsteady fuel flow prevented idle-mode performance evaluation.

Excessive oxidizer injection temperatures were not observed during the transition to post-main-stage idle mode. The maximum increase was approximately 10°F and coincided with the peak in engine ambient pressure and temperature.

An average chamber pressure of 1182 psia was attained before transition to post-main-stage idle mode. This resulted in a characteristic velocity of approximately 7740 ft/sec and a specific impulse of approximately 433 lbf-sec/lbm. The thrust was calculated to be approximately 249,000 lbf. The mixture ratio was approximately 4.9 with the propellant utilization valve in the null position (nominal mixture ratio of 5.0).

### 4.2.5 Firing J4-1001-07C

The objectives for this firing were to (1) verify stable idle-mode operation and (2) evaluate main-stage performance. The stage prevalves were open (for 45 min) until 15 min before engine start signal to precondition the propellant feed systems.

Stabilized idle-mode operation was not attained. During the initial 22 sec of operation, chamber pressure was increasing and oscillating with amplitudes up to ±1.5 psia and frequencies ranging from 1 to 2 Hz. Beginning at t-0 + 22 sec, the oscillations changed to amplitudes of ±3 psi and a frequency of 1 Hz. These oscillations continued until transition to main stage. Similar oscillations in the fuel feed systems pressures were observed with a maximum amplitude of ±12 psi recorded at the fuel pump discharge after t-0 + 22 sec. Corresponding fuel injection temperature increases of up to 100°F were observed. The thrust chamber throat external skin temperature was increasing from t-0 + 22 sec until transition to main stage. The maximum throat temperature was -184°F at main-stage start signal. Unsteady fuel flow prevented calculation of idle-mode performance.

An average chamber pressure of 1279 psia was attained before engine cutoff signal. This resulted in a characteristic velocity of approximately 7720 ft/sec and a specific impulse of approximately 434 lbf-sec/lbm. The thrust was calculated to be approximately 271,000 lbf. The propellant utilization valve was inadvertently moved to the 12-deg closed position during the transition to main stage. This resulted in a mixture ratio of approximately 5.1.

#### 4.2.6 Firing J4-1001-11A

The objectives for this firing were to (1) verify stable idle-mode operation, (2) confirm that oxidizer injection temperatures were not excessive during transition to post-main-stage idle mode, (3) evaluate main-stage performance, and (4) determine rates at which the engine propellant feed system temperatures decreased during pre-main-stage idle-mode operation. This firing was conducted at thermal conditions expected for an orbital restart mission. The oxidizer pump bearing coolant temperature (TOPBC) and the fuel pump balance piston sump temperature (TFPBS) were used as indicators of propellant turbomachinery thermal conditions. To achieve the required conditions, propellants were not admitted to the engine until 5 sec before engine start signal. Oxidizer was supplied through the propellant recirculation system until t-0 + 92.5 sec, at which time the stage oxidizer prevalve was opened. Fuel was supplied to the engine normally through the stage fuel prevalve.

Apparent valve closure in the oxidizer recirculation system resulted in abnormal oxidizer flow conditions during the initial 70 sec of idle-mode operation. Stabilized idle-mode operation was attained at t-0 + 70 sec and continued until t-0 + 80 sec. Random chamber pressure excursions up to 6 psi were observed, beginning at t-0 + 80 sec and continuing until transition into main stage at t-0 + 98 sec. Superheated propellants were present at the engine flowmeters during idle-mode operation. This prevented determination of propellant flow rates and subsequent calculation of idle-mode performance.

A premature engine cutoff was initiated at the request of the engine manufacturer because of low chamber pressure (<20 psia) immediately before transition into main stage. The firing was terminated after 1.3 sec of main-stage operation. Approximately 340 msec of sporadic oxidizer dome vibration which exceeded 150 g rms was recorded before engine cutoff signal. Liquid fuel conditions existed at the fuel injector during oxidizer dome prime (chamber pressure = 100 psia) when the excessive vibrations were first observed. The premature engine cutoff precluded the attainment of the main-stage and post-main-stage idle-mode objectives.

The rates at which the propellant feed system temperatures decreased during pre-main-stage idle-mode operation were affected by increased engine ambient pressure and temperature between 15 and 55 sec after engine start signal. The maximum cell pressure and temperature were 1.11 psia and 172°F, respectively, during this time period. The effect on thrust chamber external exit skin temperature is shown in Fig. 34. In addition, the abnormal oxidizer flow conditions also affected chilling of the oxidizer feed system. These adverse conditions precluded determination of meaningful chilldown rates.

#### 4.2.7 Firing J4-1001-11B

The objectives for this firing were to (1) verify stable idle-mode operation, (2) evaluate main-stage performance, and (3) determine the rates at which the propellant feed system temperatures decreased during idle-mode operation. The stage prevalves were open between firngs 11A and 11B until 15 min before engine start signal to precondition the propellant feed systems.

Stabilized idle-mode operation was not attained. Chamber pressure variations were observed throughout idle-mode operation. Maximum pressure excursions of 6 psi were recorded after t-0 + 47 sec. Similar variations were observed in the fuel feed system with maximum pressure oscillations of 8 psi recorded at the fuel pump discharge. Unsteady fuel flow prevented determination of idle-mode performance.

Main-stage performance was considered questionable, based on the analysis of firing 07A main-stage performance data (Ref. Section 4.2.3). No changes in the injector or pressure measurement configuration were implemented between firings 07A and 11B.

Subcooled oxidizer was present at the pump inlet and discharge and the oxidizer idle-mode supply line within 5 sec after engine start signal. Subcooled fuel was present at the pump inlet and discharge after 20 sec of idle-mode operation. Saturated or liquid conditions at the oxidizer injector existed from t-0 + 3 sec until engine cutoff signal. Superheated fuel was present at the fuel injector during idle-mode operation. Increased oscillations in the fuel injection temperature were observed to correspond with increasing thrust chamber throat external skin temperature.

### 4.2.8 Firing J4-1001-11C

The objectives for this firing were to (1) verify stable idle-mode operation, (2) evaluate main-stage performance, and (3) determine rates at which the engine propellant feed system temperatures decreased during idle-mode operation. This firing was conducted at thermal conditions expected for an orbital restart mission. The oxidizer pump bearing coolant temperature (TOPBC) and the fuel pump balance piston sump temperature (TFPBS) were used as indicators of propellant turbomachinery thermal conditions. To achieve the required conditions, propellants were not admitted to the engine until 5 sec before engine start signal.

Stabilized idle-mode operation was attained 25 sec after engine start signal and continued until 81 sec after engine start signal. The chamber pressure was increasing and oscillated with amplitudes greater than ±1 psi and frequency between 0.5 and 1 Hz during the initial 25 sec. Beginning at t-0 + 81 sec, sporadic pressure excursions up to 6 psi were observed. A 4-psi step increase in chamber pressure average level, with increased oscillations, began 89 sec after engine start signal. These oscillations, at a frequency of approximately 4 Hz with amplitudes up to ±1 psi, continued until transition into main stage. Superheated oxidizer at the flowmeter precluded determination of idle-mode performance.

A premature engine cutoff was initiated by the vibration safety cutoff system after 1.7 sec of main-stage operation. Liquid fuel conditions existed at the fuel injector at dome prime (chamber pressure = 100 psia), when the excessive oxidizer dome vibrations were first recorded. The premature cutoff precluded attainment of the main-stage objective.

Subcooled oxidizer conditions were present by t-0 + 2 sec at the pump inlet and oxidizer idle-mode supply line. Liquid oxidizer conditions were not present at the pump discharge until t-0 + 94 sec. Saturated or liquid conditions existed from t-0 + 3 sec until engine cutoff signal at the oxidizer injector. Liquid or saturated conditions were present by 20 sec after engine start signal at the fuel pump inlet and discharge. Saturated conditions at the fuel injector existed after 20 sec of idle-mode operation. The thrust chamber external skin temperatures indicated approximately -425°F after 30 sec of idle-mode operation.

#### 4.2.9 Firing J4-1001-15A

The objective of this firing was to document the transition from idle mode to main stage with the solid-propellant turbine starter ignition signal delayed 0.5 sec after main-stage start signal (normally the ignition signal is initiated at main-stage start signal). The stage prevalves were open for approximately 60 min before engine start signal to precondition the propellant feed system.

The ignition delay of 0.502 sec after main-stage start signal was sufficient to allow the main oxidizer valve to open to its first stage position and the hot gas tapoff valve to attain its maximum opening before the solid-propellant turbine starter ignited. Tapoff manifold and fuel turbine inlet temperatures indicated that hot gas from the combustion chamber entered the fuel turbine before the delayed ignition signal. However, there was no significant increase in fuel turbine speed until the solid-propellant turbine starter ignited.

Engine conditions at engine start signal were essentially the same as for firings 06A and 15A of this series. The fuel pump inlet pressure was 29.9 psia for firing 15A, and 33.0 psia for firing 06A. The solid-propellant turbine starter ignition signal was not delayed for firing 06A. Comparison of solid-propellant turbine starter chamber pressures on these two firings revealed that the initial peak was 200 psi greater with the ignition delay. This resulted in a faster increase in fuel pump speed and a shorter time to oxidizer dome prime relative to the ignition signal. Oxidizer dome prime (combustion chamber pressure = 100 psia) occurred approximately 0.9 sec after the delayed ignition signal as opposed to 1.1 sec without the delay. Programmed engine cutoff signal at main-stage control signal of firing 15A was initiated before the solid-propellant turbine starter had completed burning. Between oxidizer dome prime and main-stage control signal, the combustion chamber pressure histories for these two firings were essentially the same. The maximum chamber pressure at main-stage control signal was approximately 330 psia with the delayed ignition signal, and 310 psia without the ignition delay. The fuel pump speeds differed by approximately 200 rpm at main-stage control signal; the pump speed was approximately 15,800 rpm for the delayed ignition firing (15A).

#### 4.2.10 Firing J4-1001-15B

The objectives of this firing were to (1) evaluate the effect of a 0.911-in. oxidizer idle-mode supply line orifice on the rate at which the thrust chamber temperatures increased during idle mode with high (44 psia) oxidizer and low (28 psia) fuel pump inlet conditions and (2) to document the effect of a 0.911-in. oxidizer idle-mode supply line orifice on transition to main stage employing a delayed ignition signal to the solid-propellant turbine starter. The thrust chamber was prechilled to -187°F at engine start signal. The stage prevalves were closed 30 min before engine start signal after having been open for approximately 30 min.

Previous firings (J4-1001-13B, -13C, and -14B) which had comparable objectives are found in Ref. 8. Firings J4-1001-13B and -13C were conducted with a 1.033-in. oxidizer idle-mode supply line orifice; firing J4-1001-14B utilized a 0.977-in. orifice (Ref. 8). Each of these firings was prematurely terminated as a result of excessive thrust chamber throat external skin temperature. The established temperature limit was 300°F for both 13B and 13C, but was lowered to 250°F for both 14B and 15B. The following table summarizes the significant variables and results.

| Firing J4-1001- | 13B | 13C | 14A | 15B |
|---|---|---|---|---|
| Oxidizer pump discharge pressure, psia | 44.0 | 45.3 | 43.5 | 44.5 |
| Fuel pump discharge pressure, psia | 21.5 | 29.9 | 30.8 | 30.0 |
| Oxidizer idle-mode supply line orifice, in. | 1.033 | 1.033 | 0.977 | 0.911 |
| Thrust chamber throat temperature at t-0, °F | 34 | 80 | -200 | -187 |
| Propellants on engine, min | 70 | 60 | 70 | * |
| Time to 250°F, thrust chamber, sec | 17 | 21 | 46 | ** |
| Maximum thrust chamber heatup rate, °F/sec | 22 | 15 | 17 | 6 |

* For 30 min, prevalves closed 30 min before engine start.
** Maximum temperature attained was 10 °F.

Transition to main stage was smooth and stable. Programmed engine cutoff occurred at main-stage control signal. The delayed ignition signal to the solid-propellant turbine starter resulted in start transient effects similar to those experienced during firing 15A as stated in Section 4.2.9.

### 4.2.11 Firing J4-1001-15C

The objective for this firing was to demonstrate stable transition to main stage after 100 sec of idle mode with low (34 psia) oxidizer and nominal (33 psi) fuel pump inlet pressures, a 0.911-in. oxidizer idle-mode supply line orifice, and a delayed ignition signal to the solid-propellant turbine starter. This firing was conducted at thermal conditions expected for an orbital restart mission. The oxidizer pump bearing coolant temperature (TOPBC) and the fuel pump balance piston sump temperature (TFPBS) were used as indicators of propellant turbomachinery thermal conditions. To achieve the required conditions, propellants were not admitted to the engine until 5 sec before engine start signal.

Chamber pressure steadily increased until approximately 92.5 sec after engine start signal. At this time, there was a step increase of 4 psi in the average level of chamber pressure. Subcooled fuel conditions were attained at the fuel flowmeter after approximately 92.5 sec of idle-mode operation. Subcooled oxidizer was not attained at the oxidizer flowmeter until approximately 2.5 sec later. Saturated (mixed phase) propellants existed at the injector from t-0 + 20 sec until transition into main stage.

A premature engine cutoff was initiated after 1.8 sec of main stage by the vibration safety cutoff system. Liquid fuel conditions existed at the fuel injector during oxidizer dome prime when the excessive vibrations were first observed.

## 4.3 ENGINE DAMAGE

Examination of the thrust chamber combustion zone after test 07A revealed hairline cracks in several of the thrust chamber tubes. This damage was insufficient to require immediate repair.

Extensive thrust chamber damage was sustained during test period J4-1001-09 and J4-1001-13, Ref. 8. This damage was repaired before tests J4-1001-11 and -15 of this series, but these repairs did not return the engine to an as-designed configuration. Small tube leaks and internal/external surface irregularities existed which may have altered specific tube fuel flow and heat transfer rates.

Examination of the injector assembly after test period J4-1001-15 by the engine manufacturer revealed that excessive leakage existed between the chamber pressure measurement tap and the fuel injection pressure measurement tap. Main-stage duration was insufficient to evaluate the probable error in chamber pressure data presented for test period J4-1001-15. However, the response and trend of the data are indicative of the engine start transient.

# SECTION V
# SUMMARY OF RESULTS

The results of the eleven firings of the J-2S rocket engine which were conducted during tests J4-1001-06, -07, -11, and -15 on August 25, 28, September 17, and October 29, 1969, respectively, are summarized as follows:

1. Brief durations (<20 sec) of stable idle-mode operation (chamber pressure oscillations $< \pm 1$ psi) were achieved.

2. Oxidizer injection temperatures exhibited insignificant increases ($<10^\circ$F) during transition to post-main-stage idle-mode operation.

3. The maximum rate at which the thrust chamber temperature increased during idle-mode operation with high (45-psia) oxidizer and low (27-psia) fuel pump inlet conditions was approximately 6°F/sec.

4. Three firings which were conducted at oribital restart conditions were prematurely terminated during the transition to main stage by the vibration safety cutoff system. Liquid fuel conditions existed at the injector during dome prime (chamber pressure = 100 psia) when the excessive vibrations were first observed.

5. The 0.5-sec solid-propellant turbine starter ignition delay produced higher peak starter chamber pressure, a faster increase in fuel pump speed, and a shorter time to oxidizer dome prime (relative to the ignition signal) compared to a firing with no ignition delay.

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# APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS

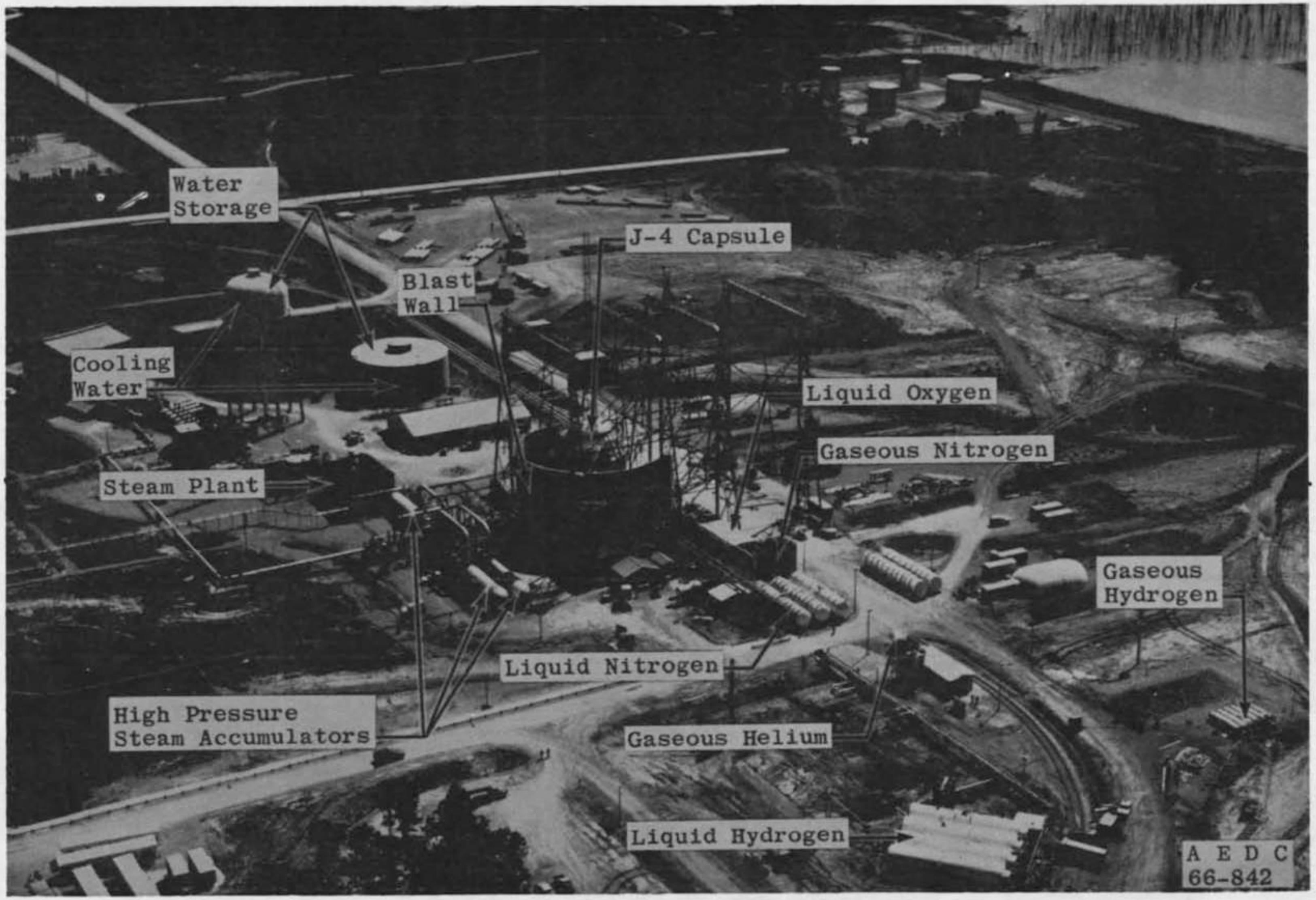



Fig. 1 Test Cell J-4 Complex

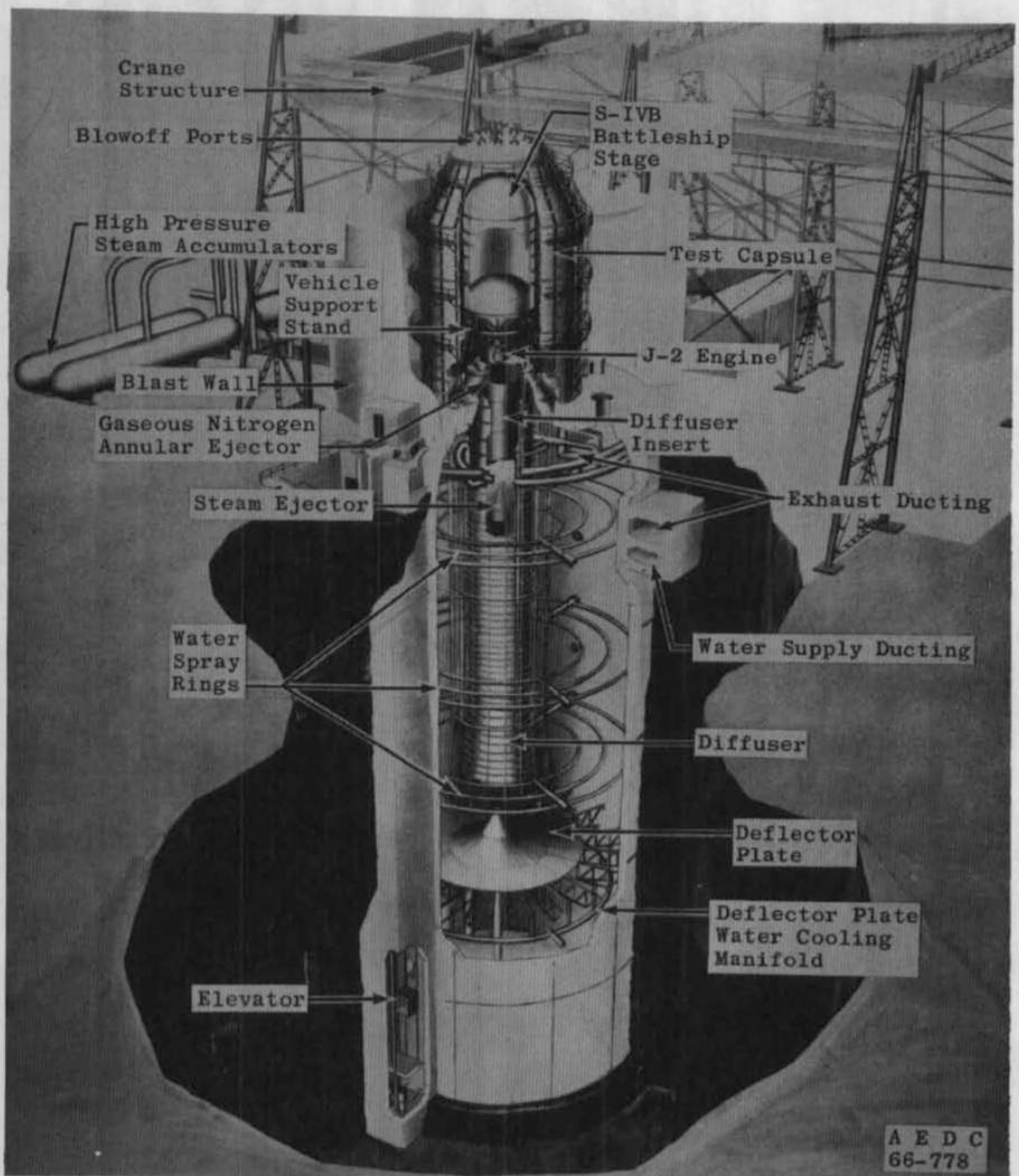



Fig. 2 Test Cell J-4, Artist's Conception

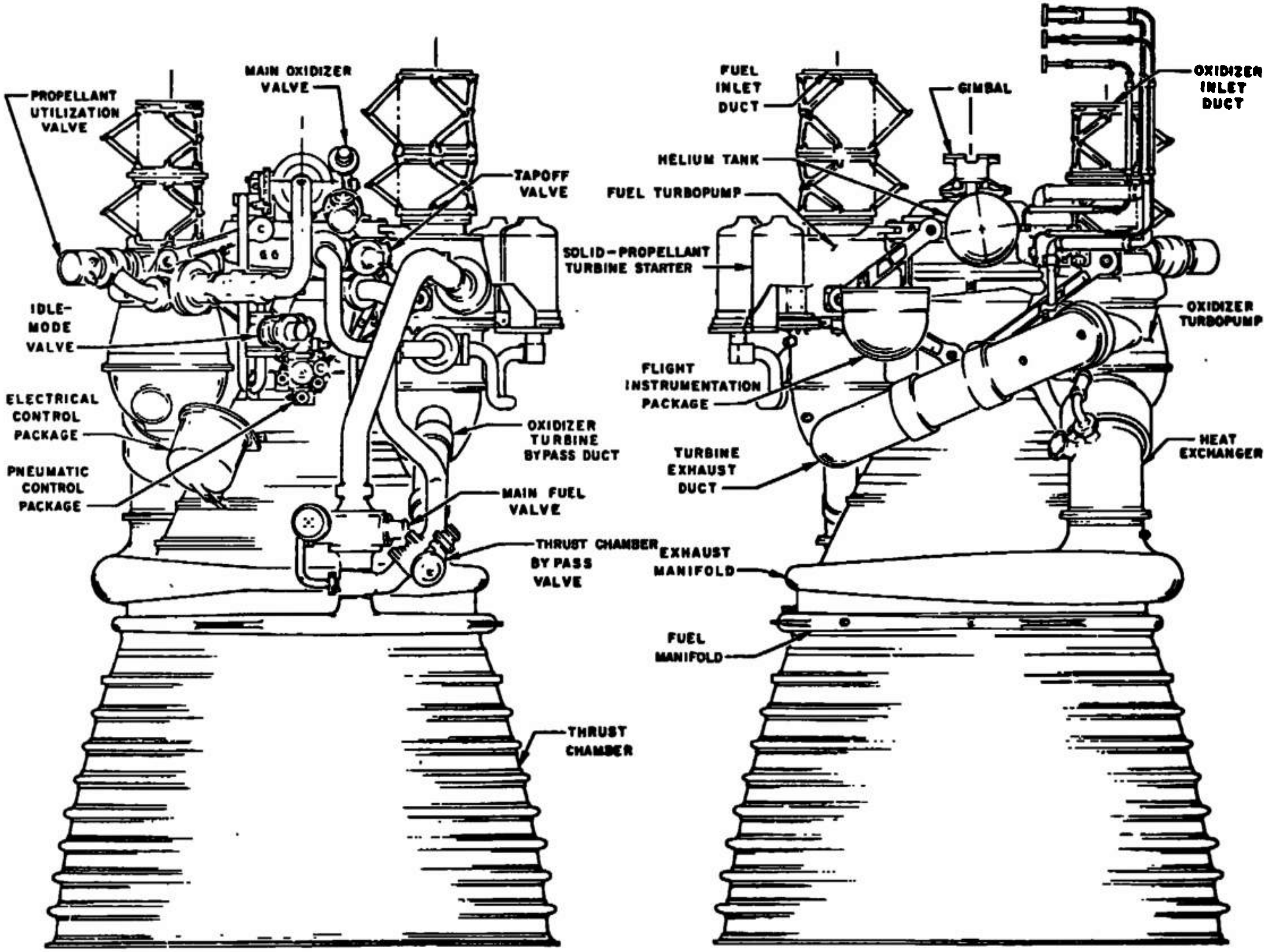



Fig. 3 J-2S Engine General Arrangement

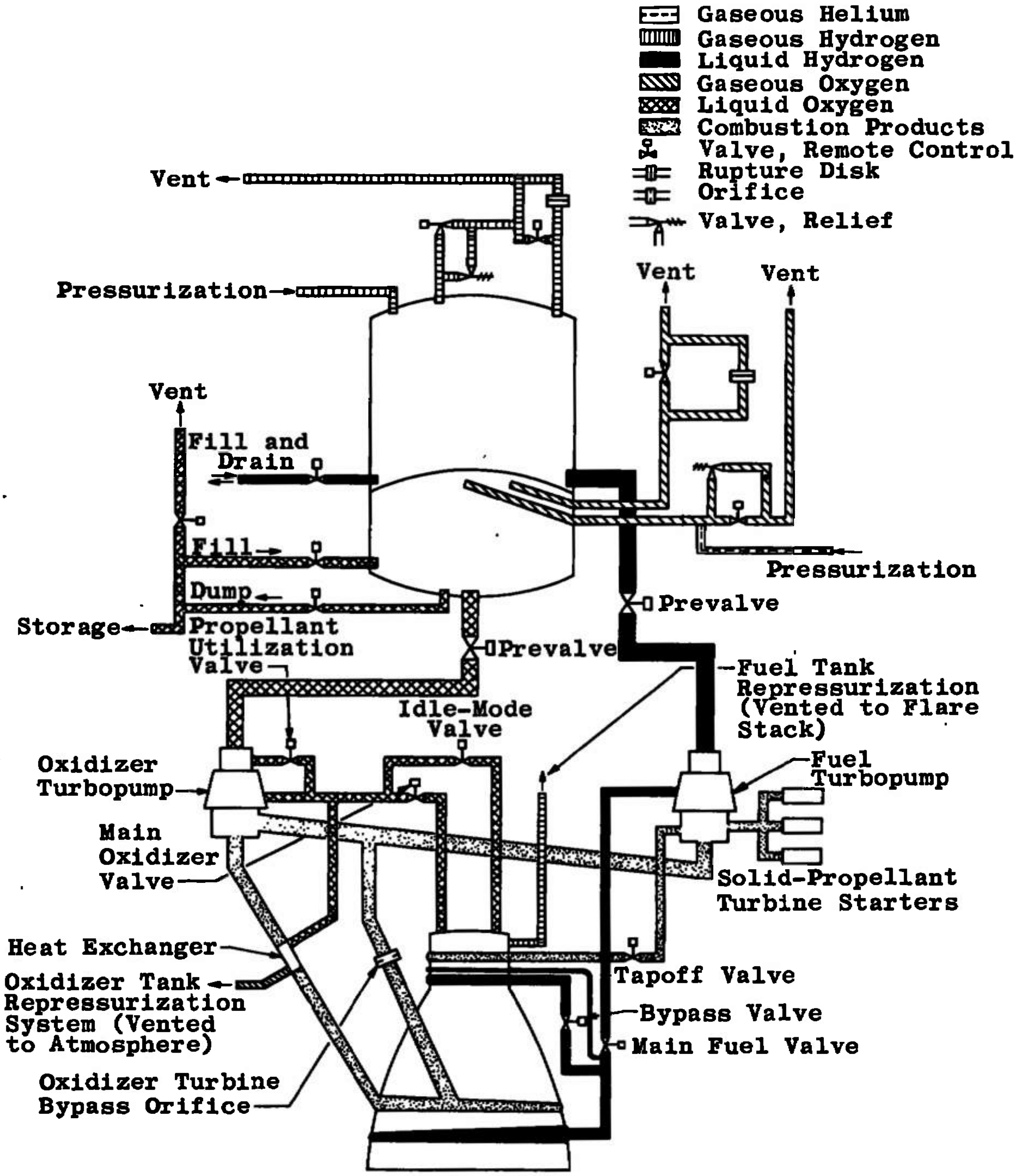
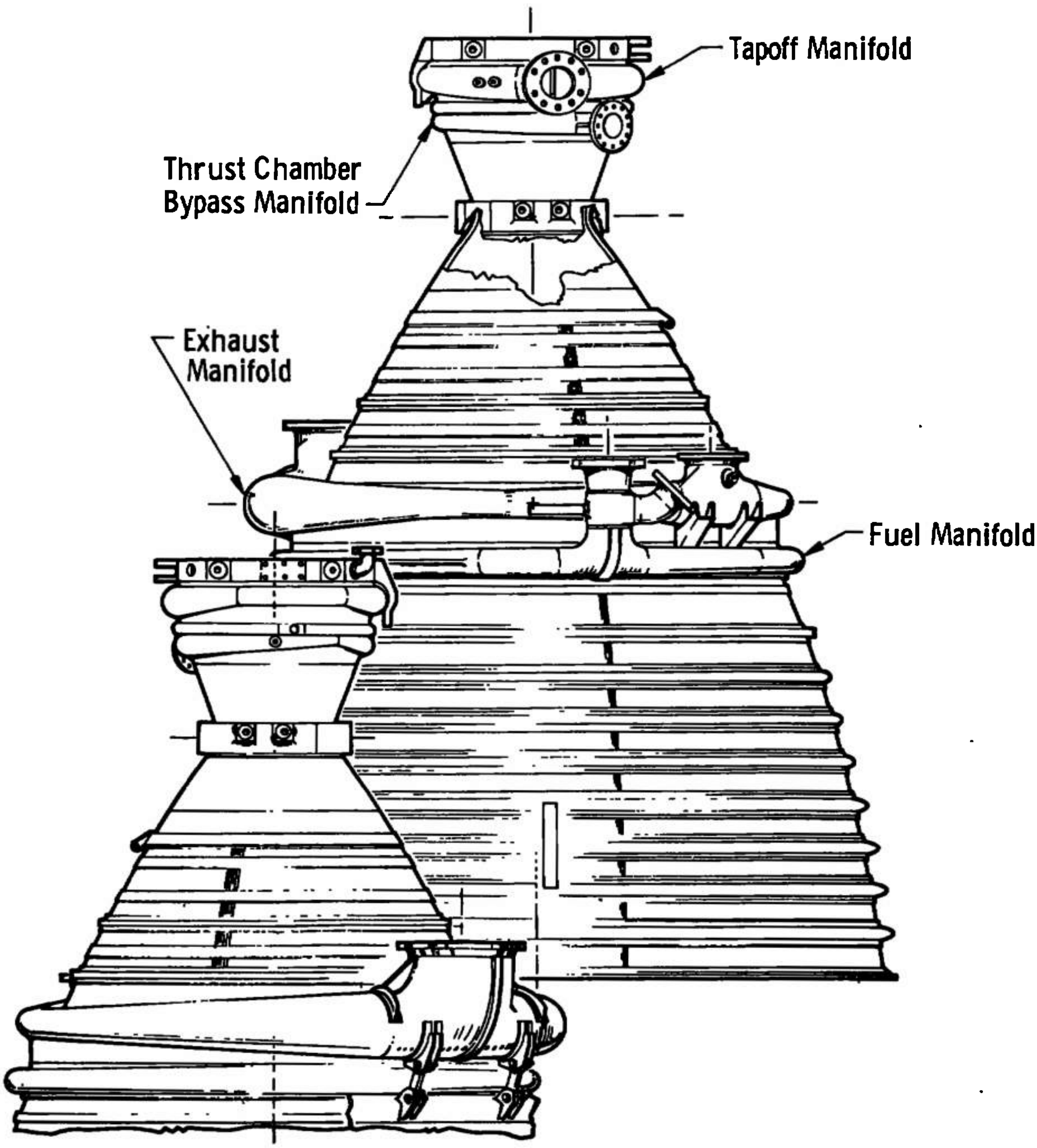
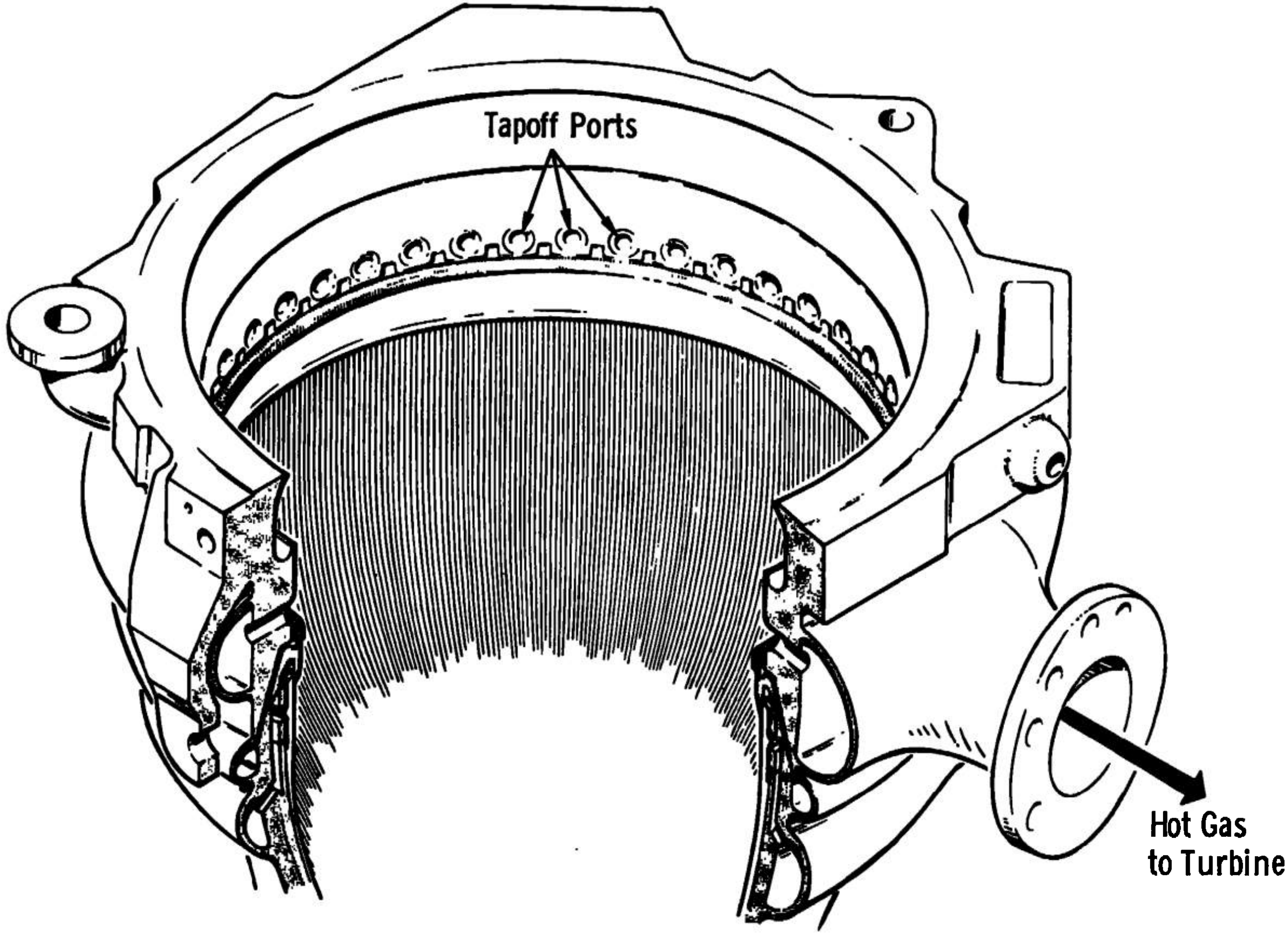


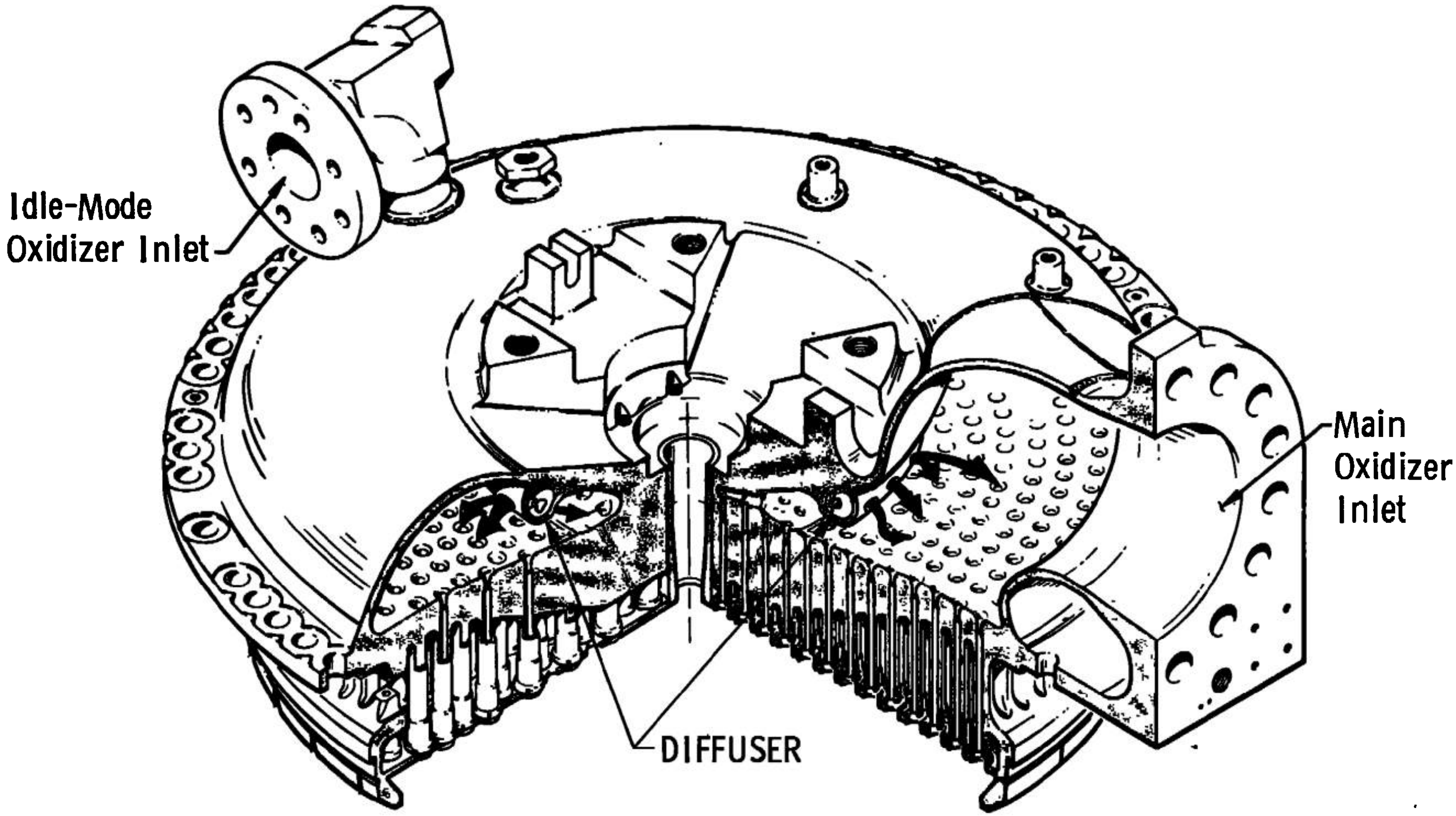

Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



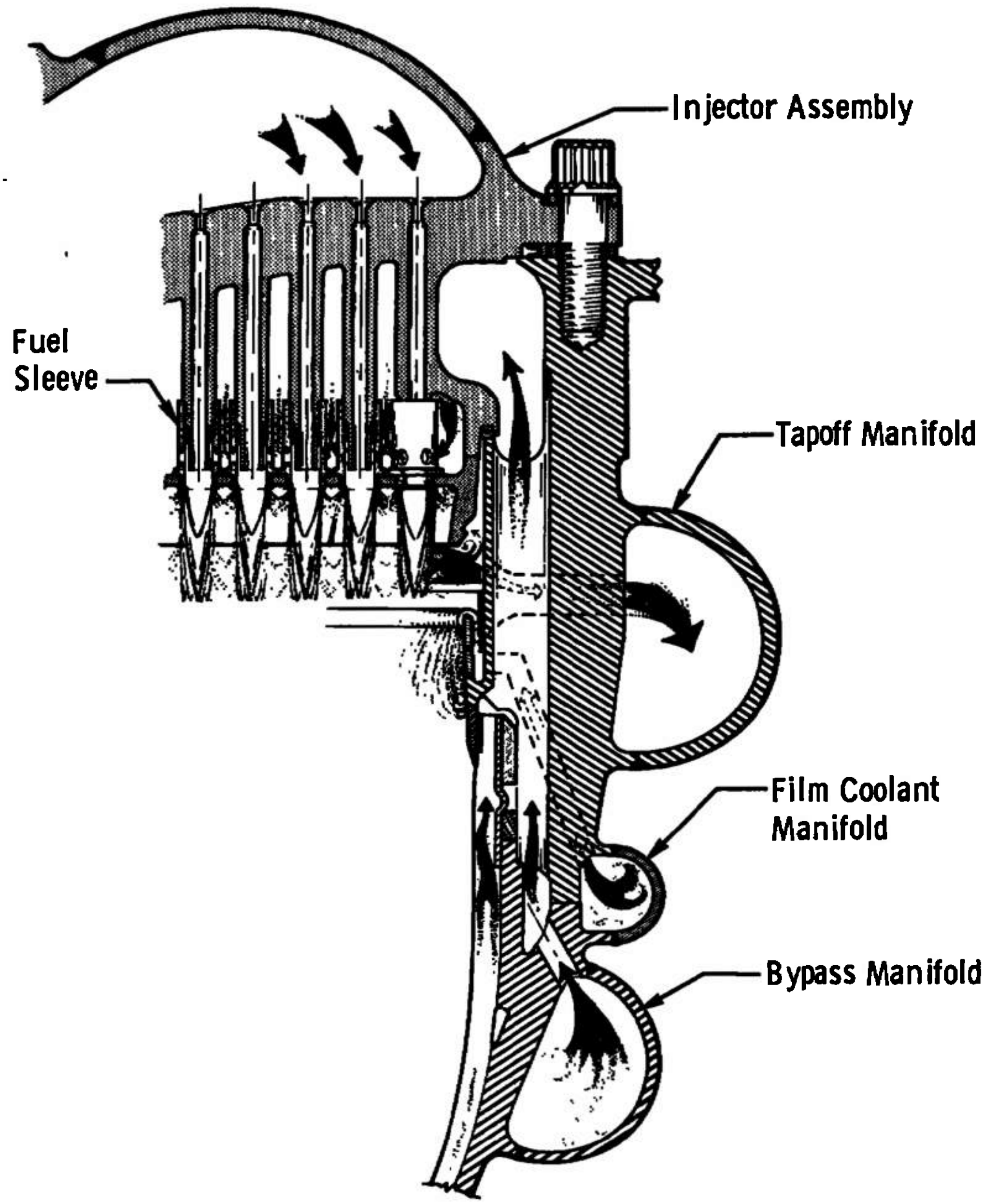

a. Thrust Chamber
Fig. 5 Engine Details




b. Combustion Chamber
Fig. 5 Continued




c. Full-Face Oxidizer Flow Injector Configuration
Fig. 5 Continued




d. Injector to Chamber
Fig. 5 Concluded

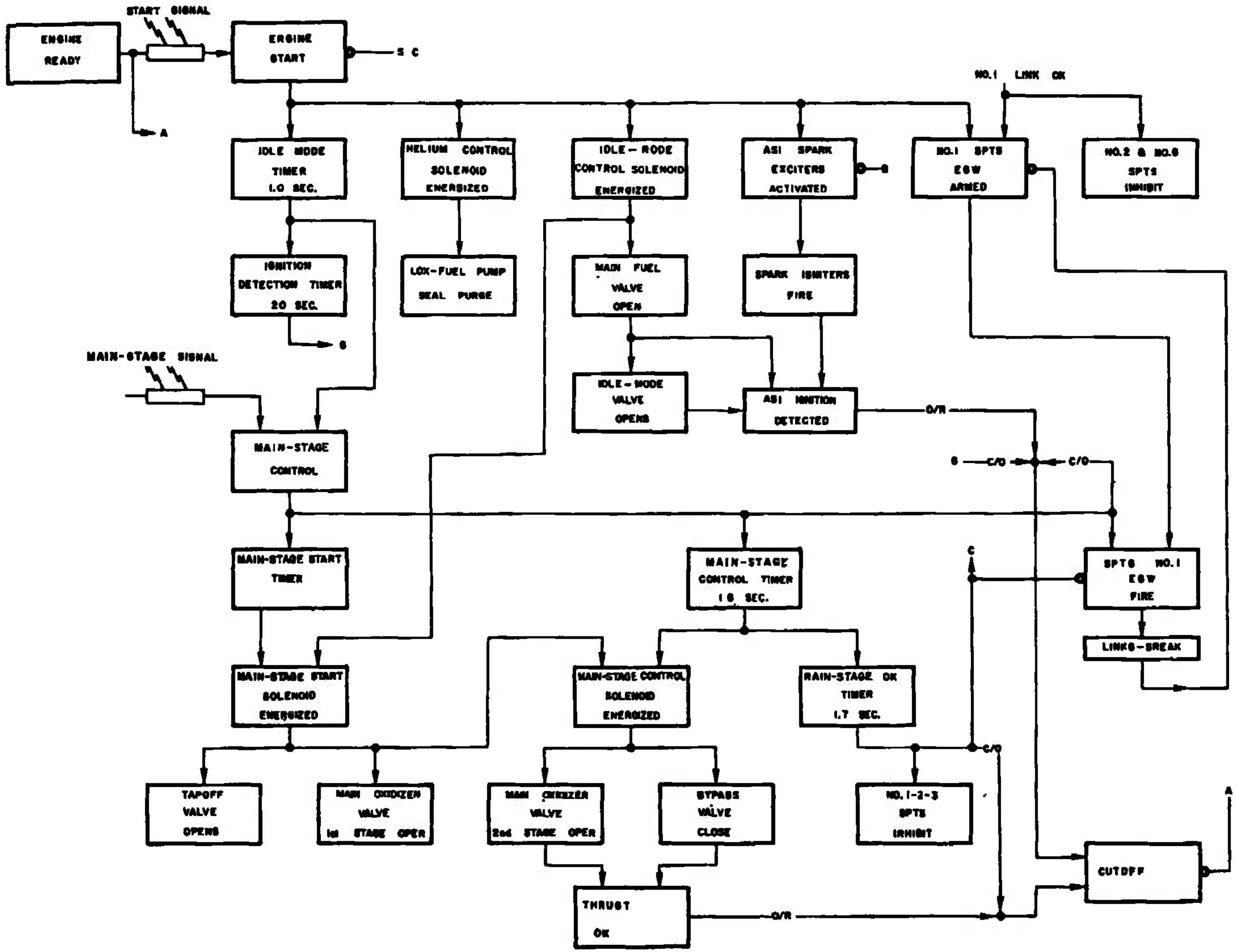
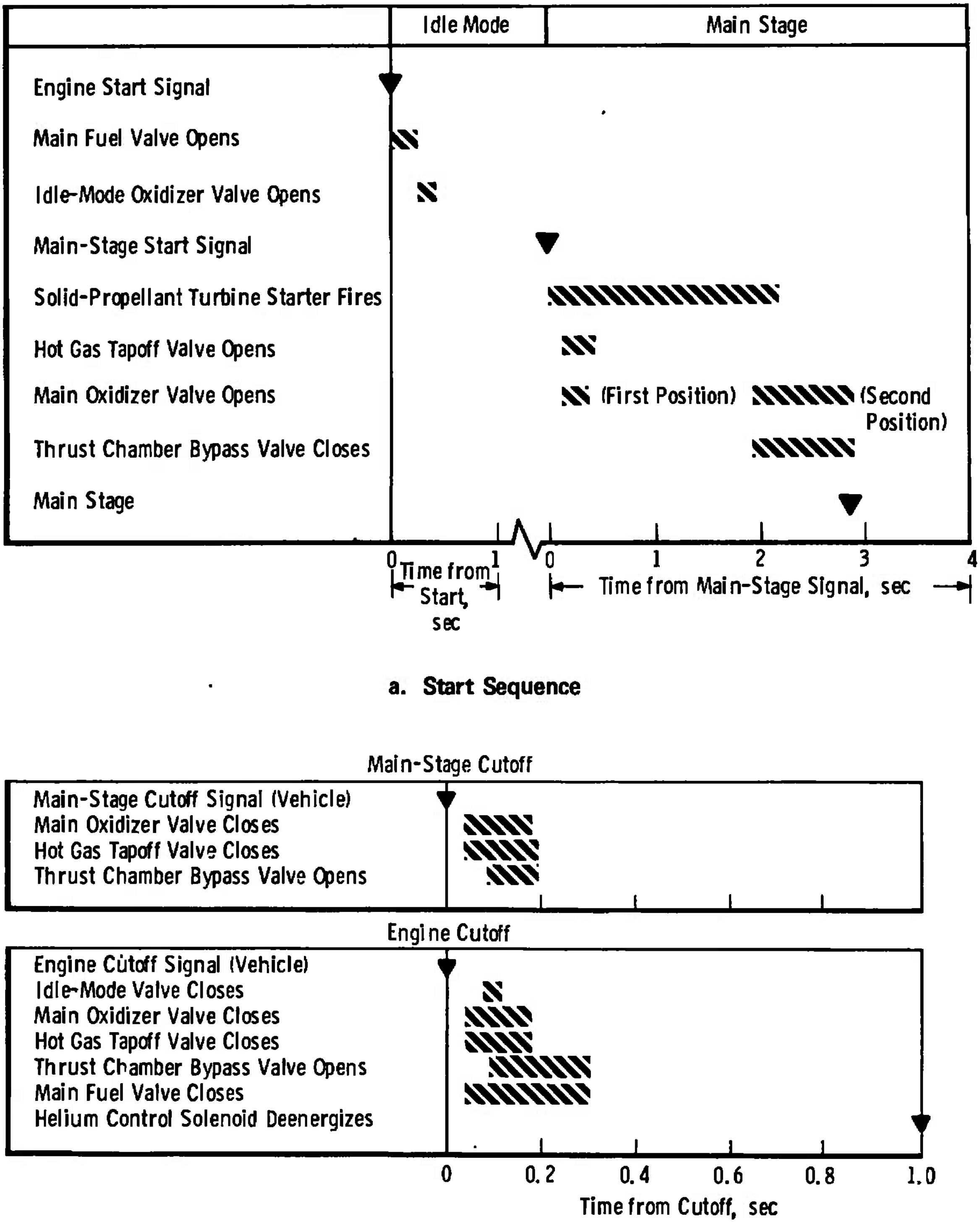



Fig. 6 Engine Start Logic Schematic

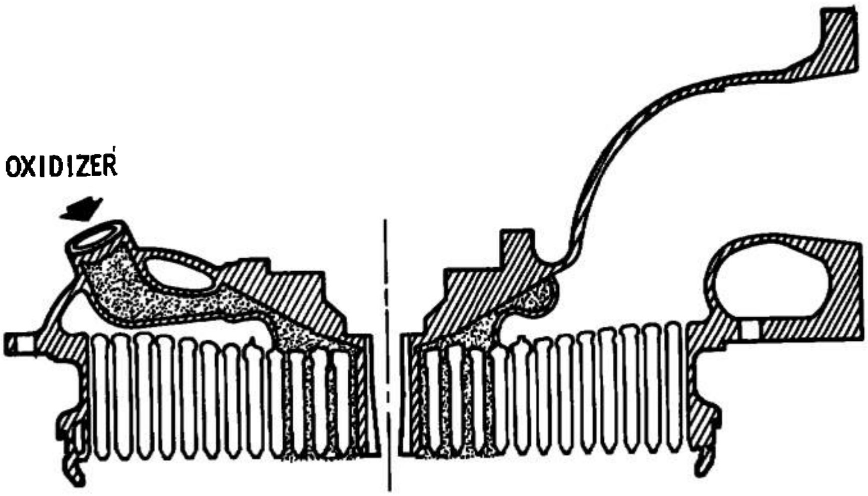



a. **Start Sequence**

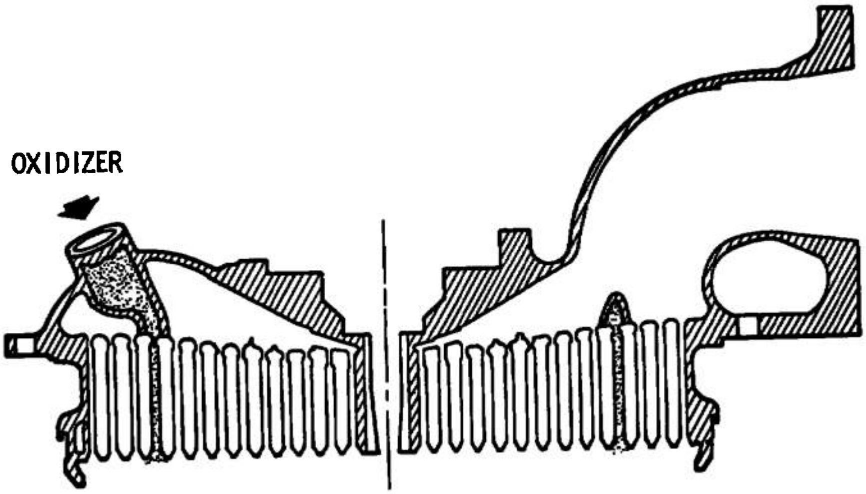


b. **Shutdown Sequence**

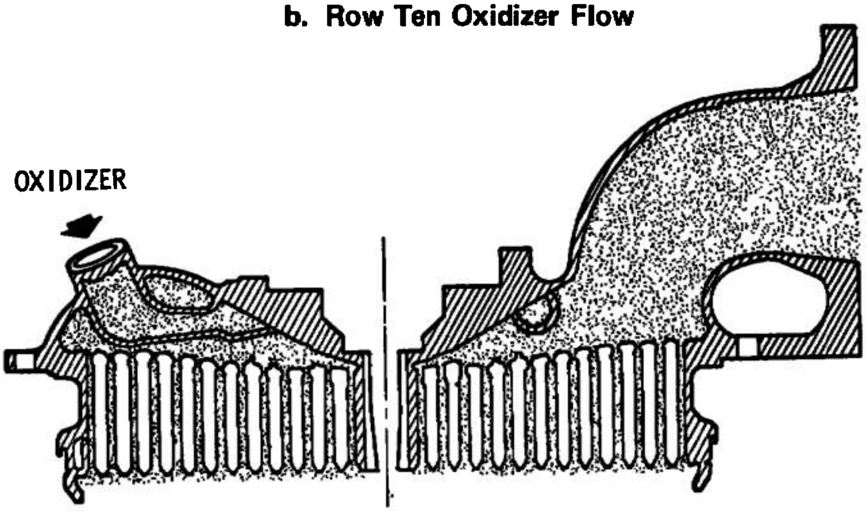
**Fig. 7 Engine Start and Shutdown Sequence**



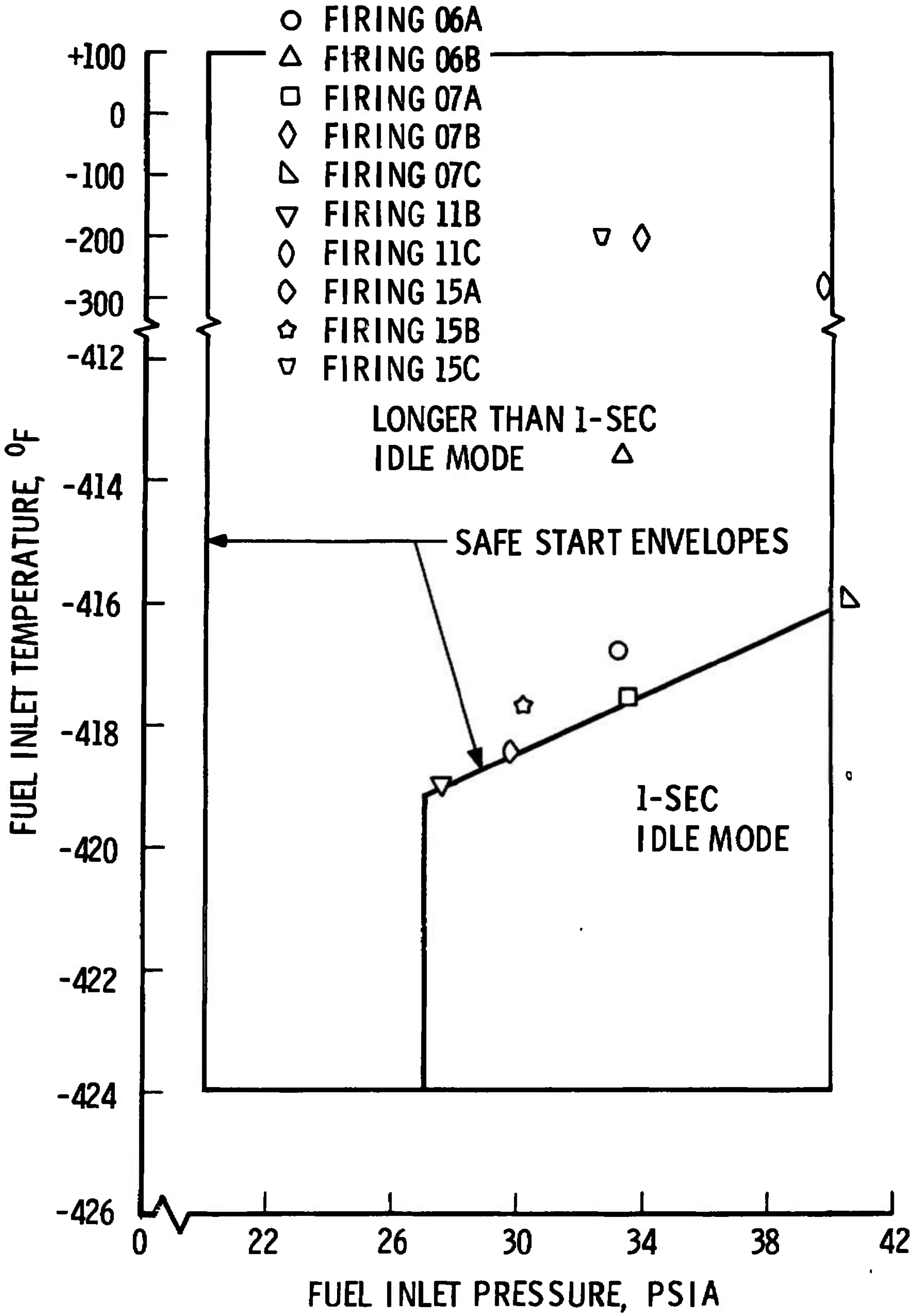

a. Inner Four Row




b. Row Ten Oxidizer Flow

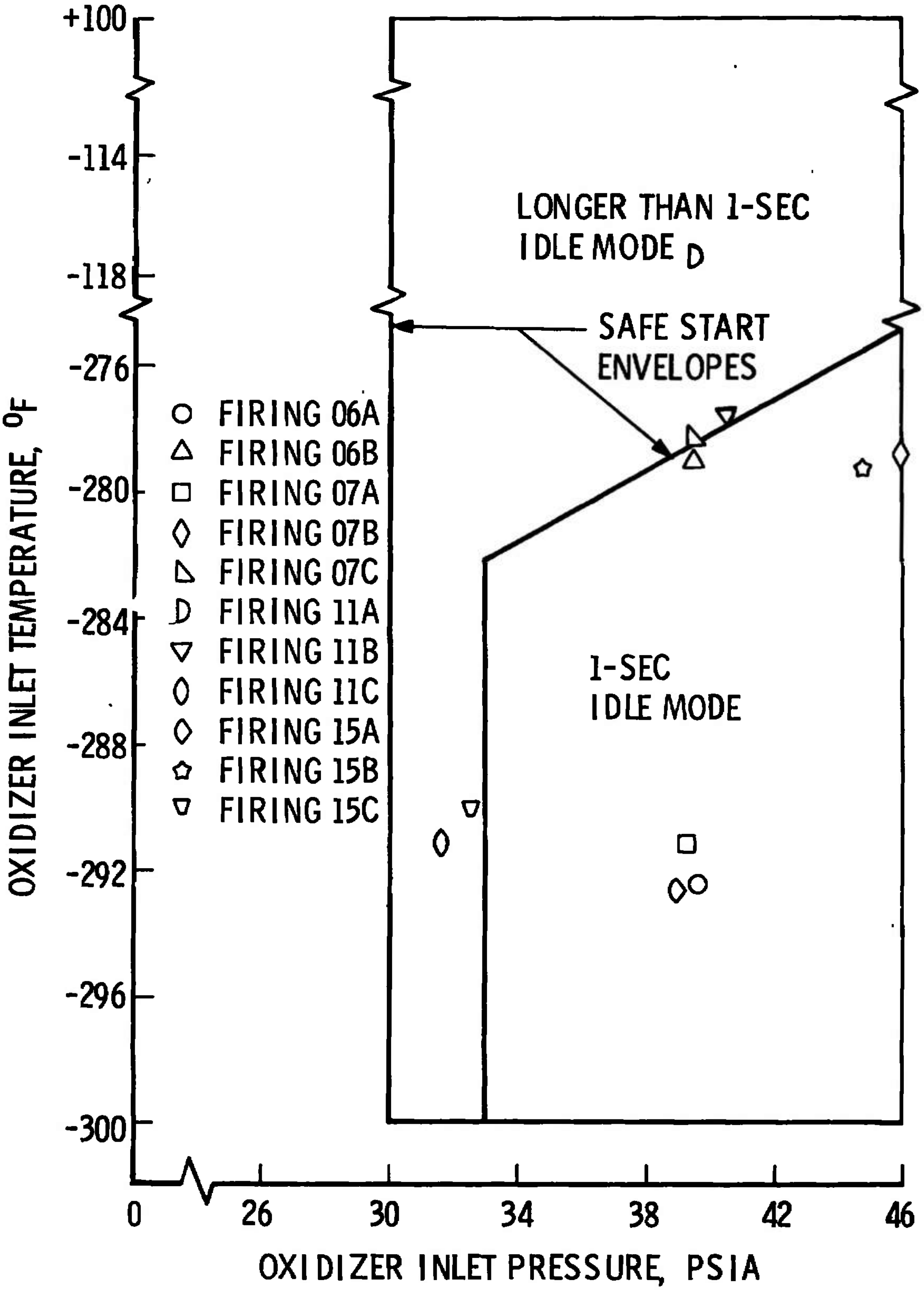



c. Full-Face Oxidizer Flow
Fig. 8 Injector Configurations

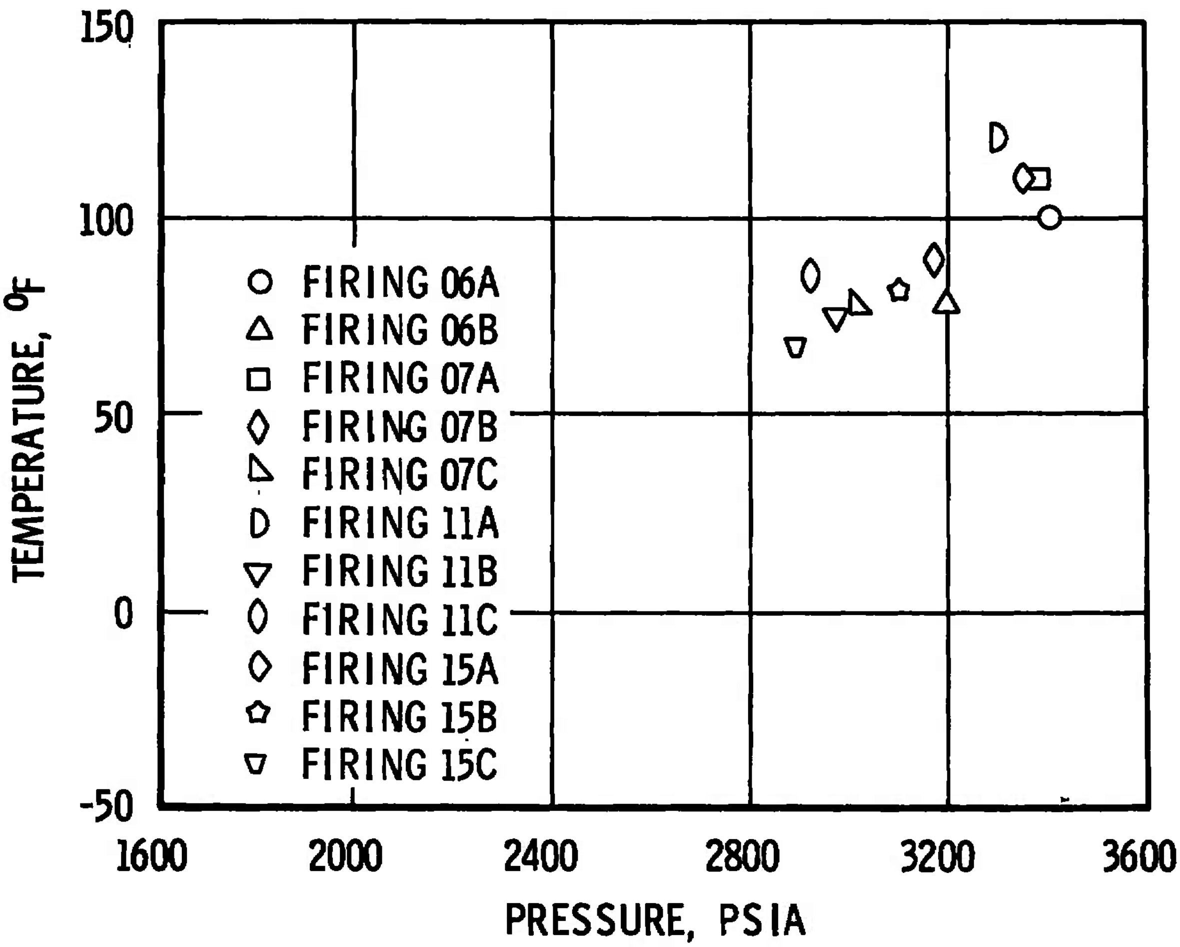



a. Fuel Pump

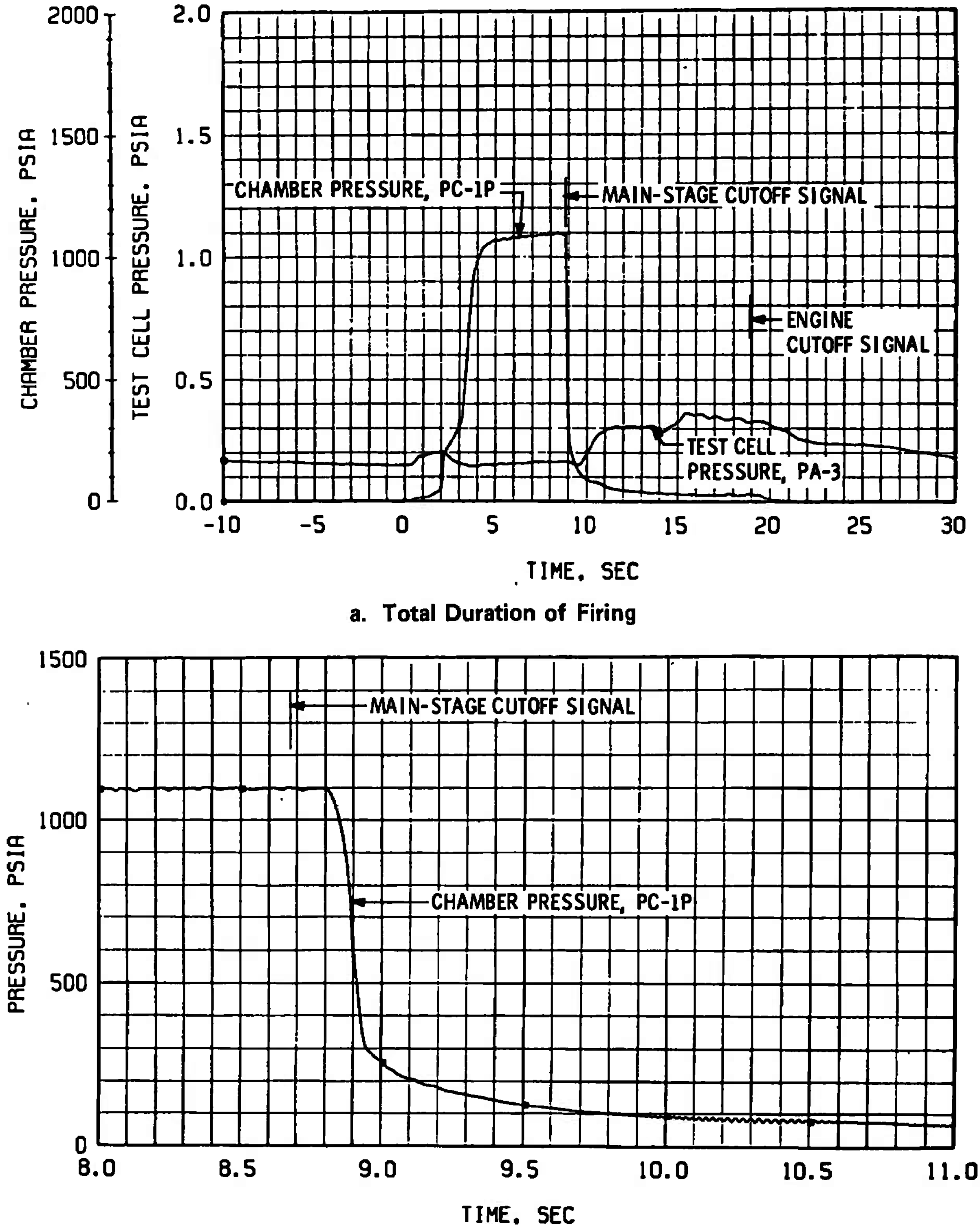
Fig. 9 Engine Start Conditions for Propellant Pump Inlets and Helium Tank




b. Oxidizer Pump
Fig. 9 Continued




c. Helium Tank
Fig. 9 Concluded

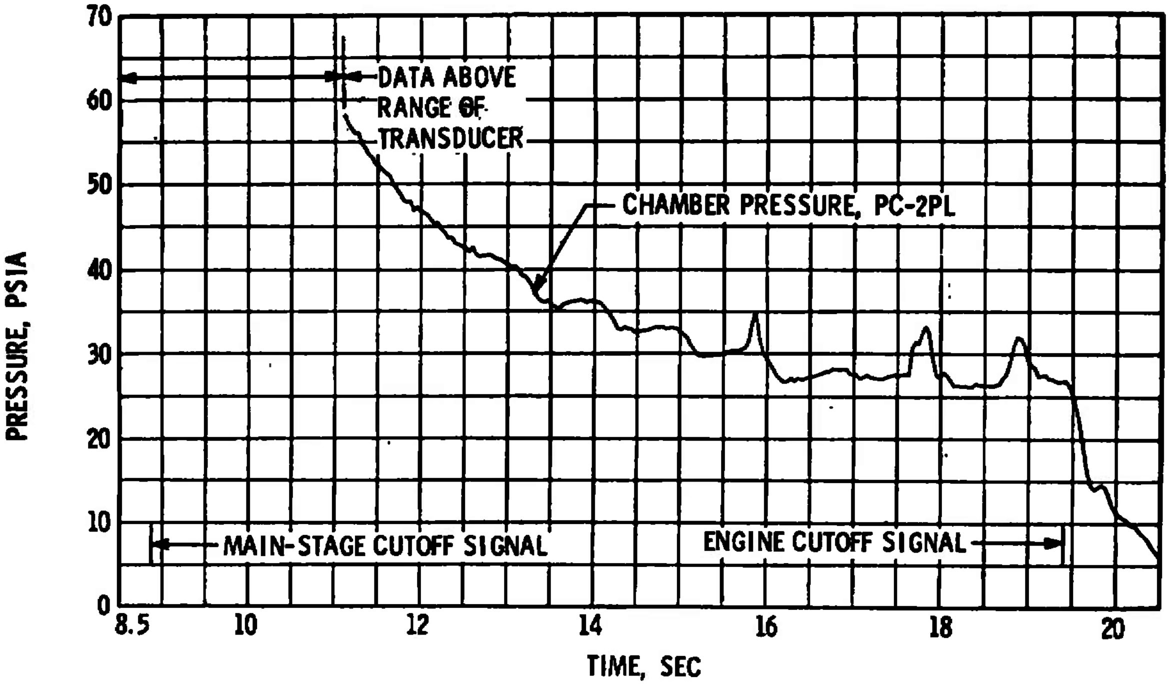



a. Total Duration of Firing



b. Transition to Post-Main-Stage Idle Mode

Fig. 10 Engine Ambient and Combustion Chamber Pressure, Firing 06A




c. Post-Main-Stage Idle Mode
Fig. 10 Concluded

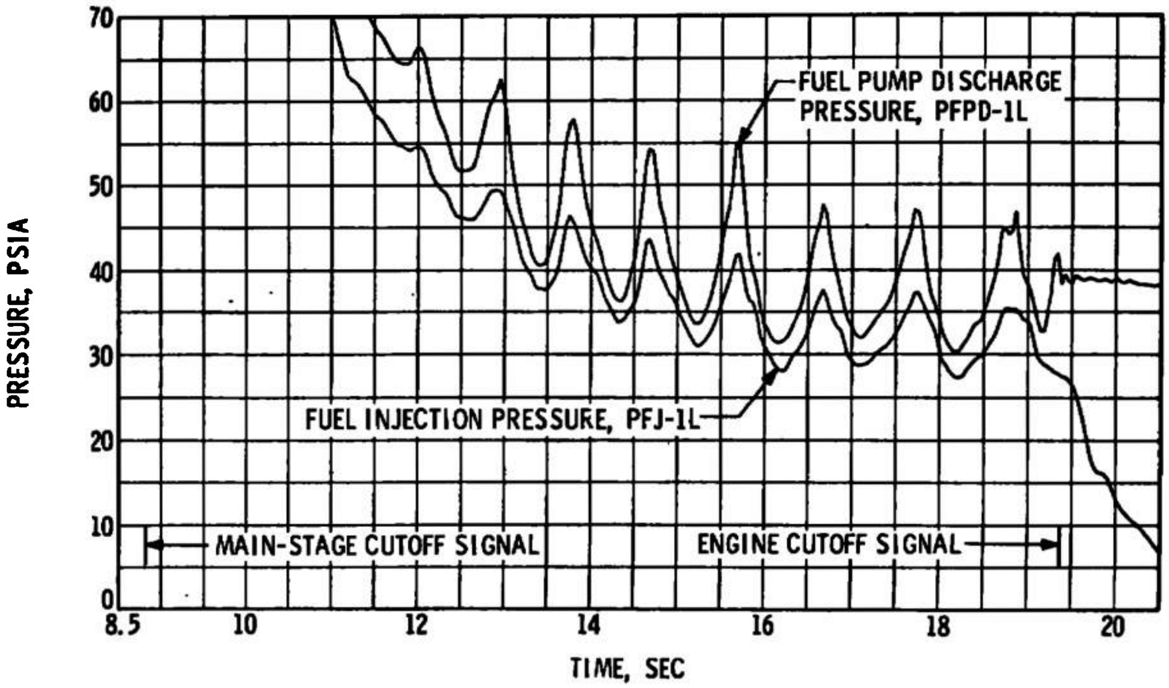



Fig. 11 Fuel Feed System Pressures during Post-Main-Stage Idle Mode, Firing 06A

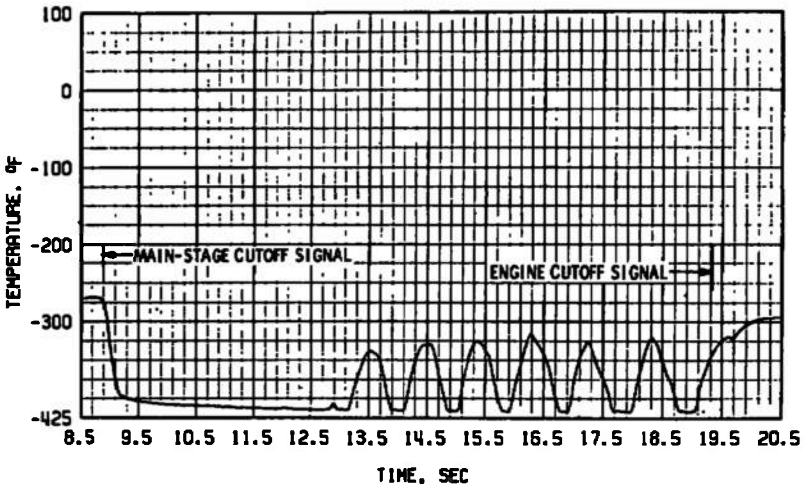



Fig. 12 Fuel Injection Temperature during Post-Main-Stage Idle Mode, Firing 06A

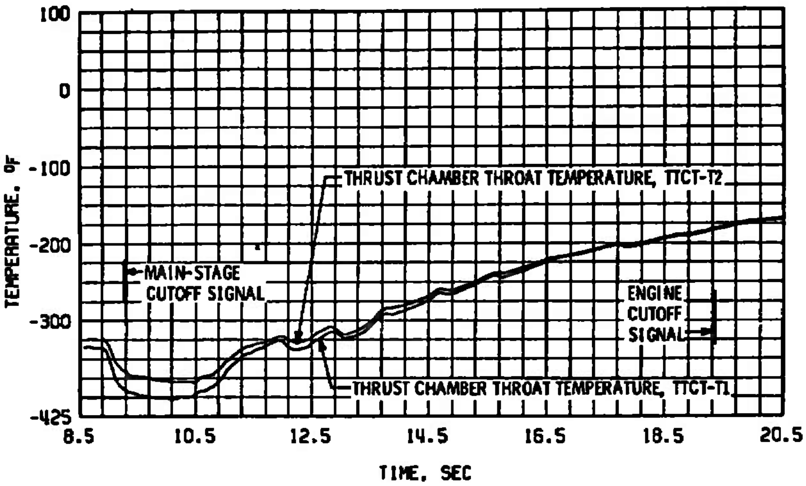



Fig. 13 Thrust Chamber Throat External Skin Temperatures, Firing 06A

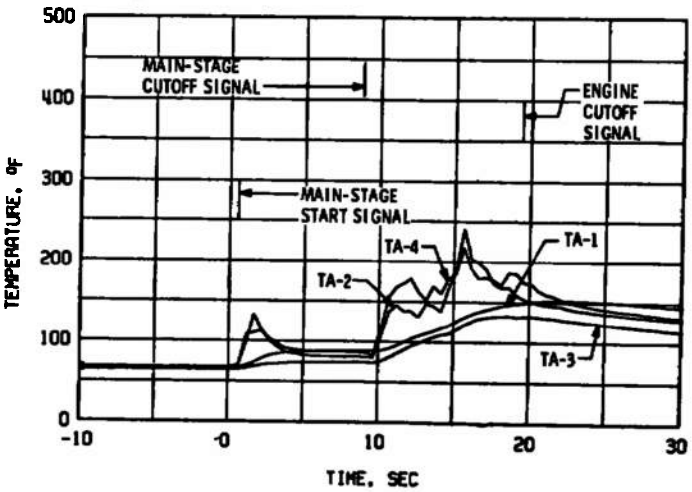
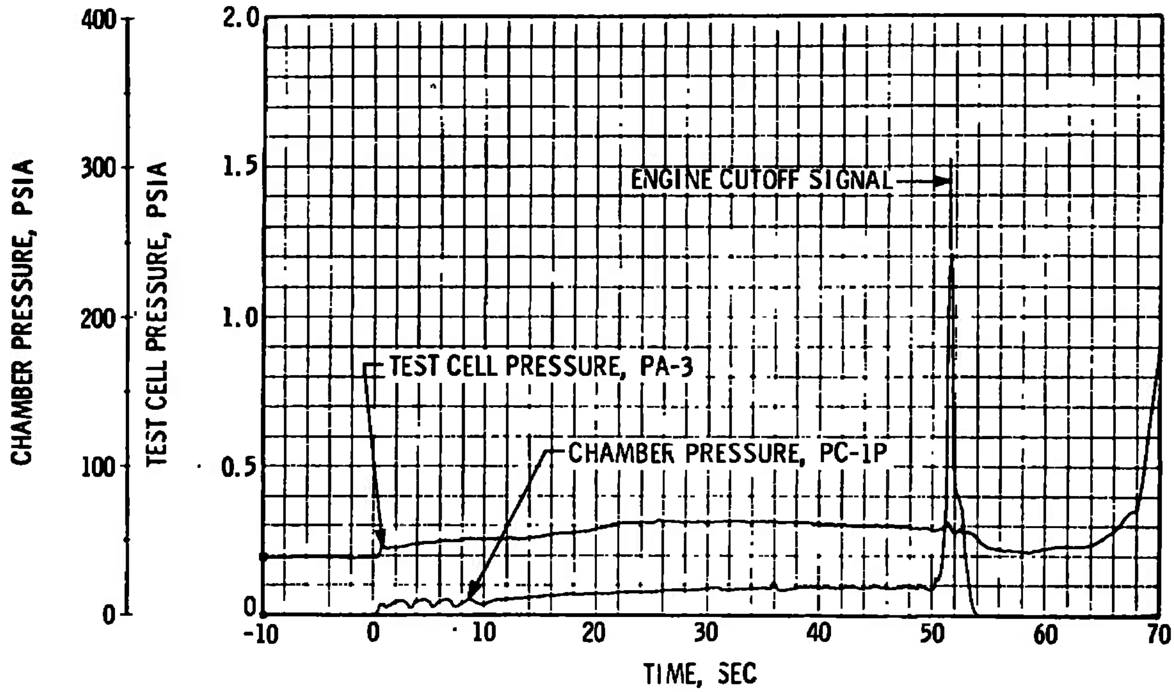
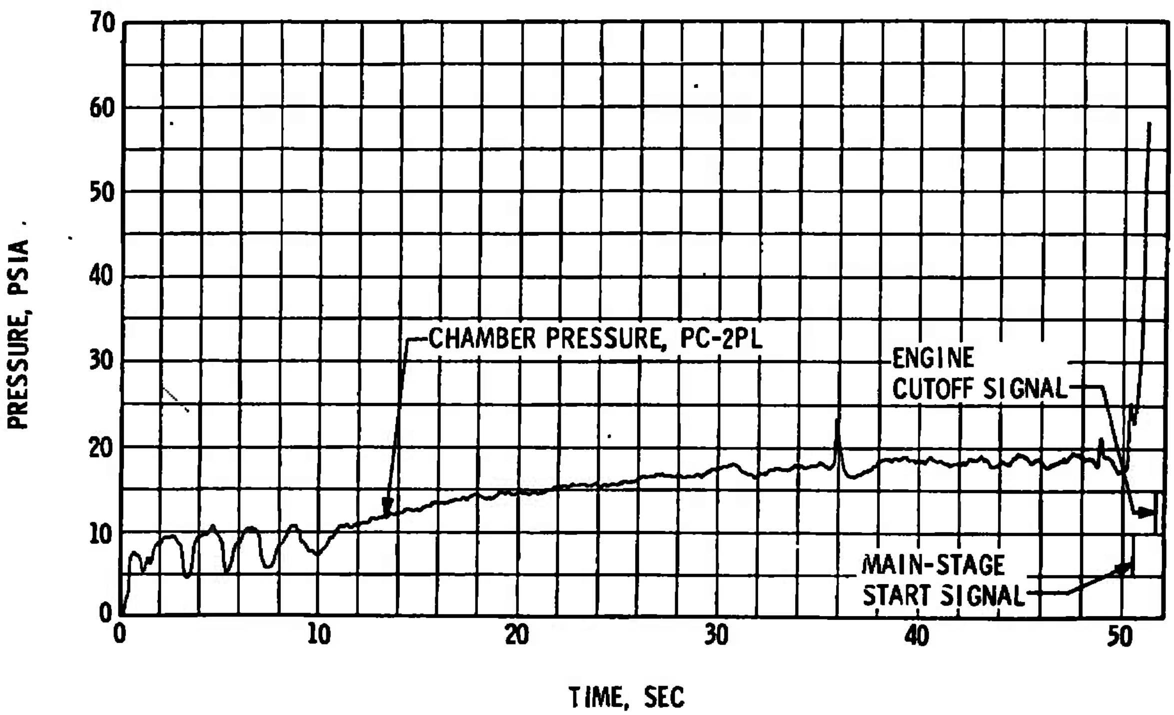



Fig. 14 Engine Ambient Temperature, Firing 06A




a. Total Duration of Firing




b. Pre-Main-Stage Idle Mode

Fig. 15 Engine Ambient and Combustion Chamber Pressure, Firing 06B

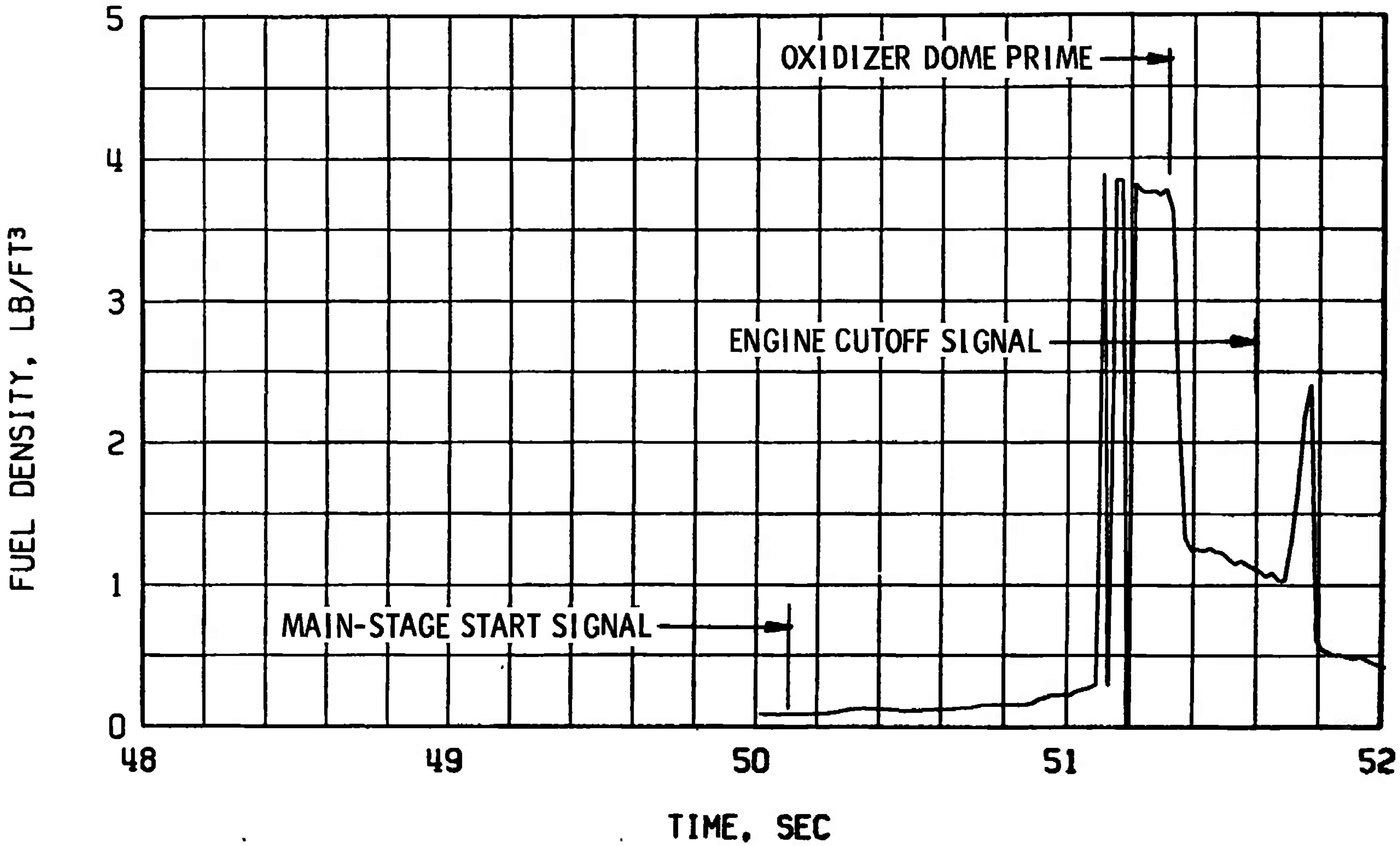
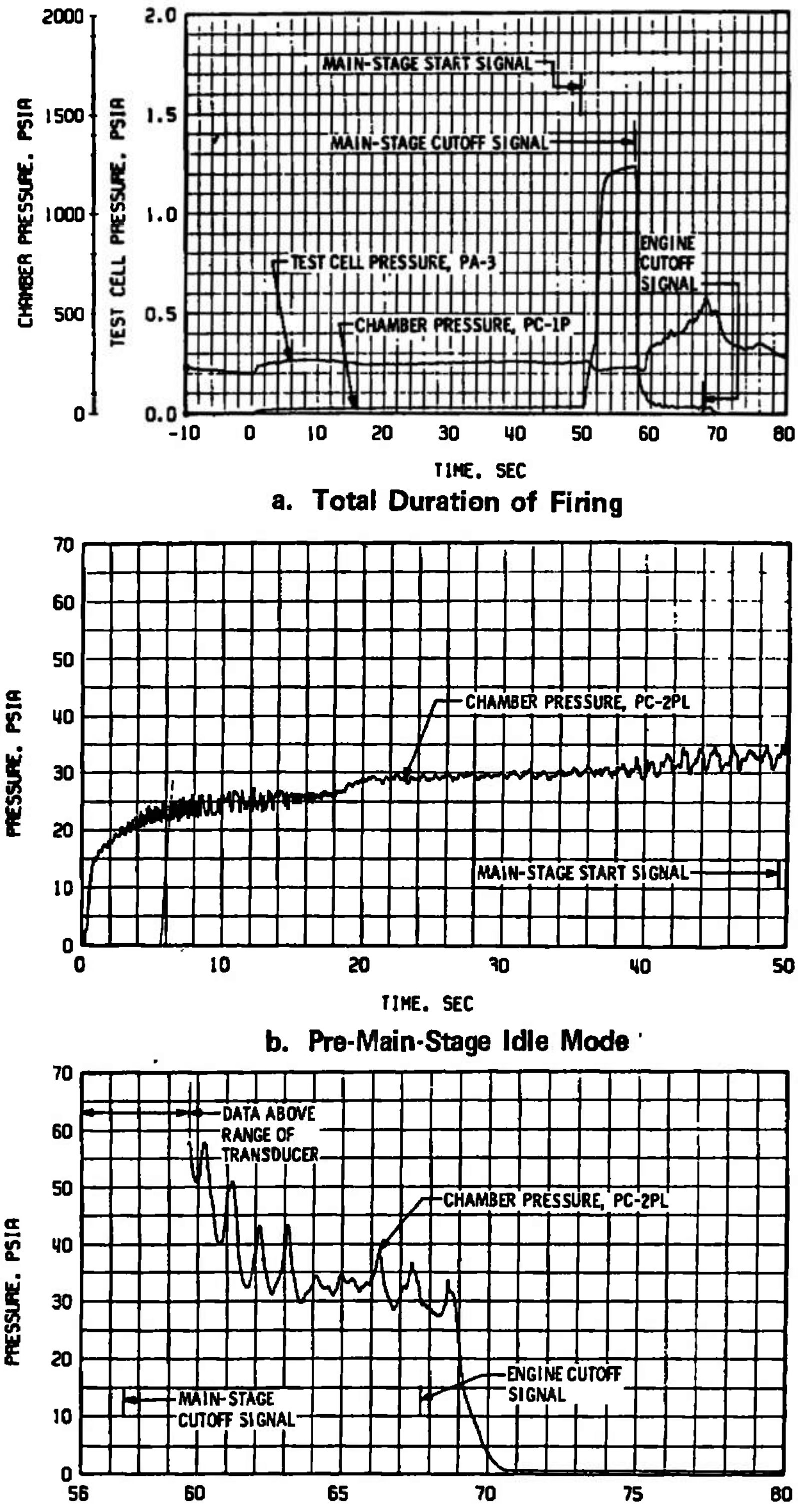



Fig. 16 Fuel Density at the Fuel Injector during Transition, Firing 06B




a. Total Duration of Firing

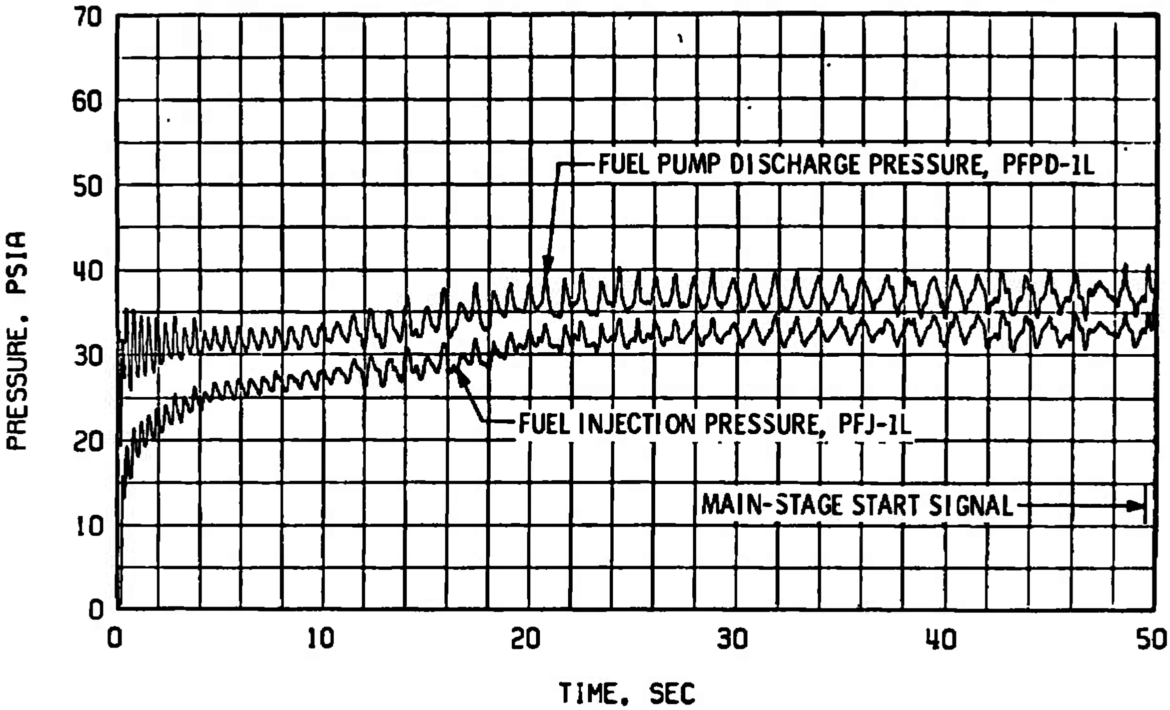


b. Pre-Main-Stage Idle Mode

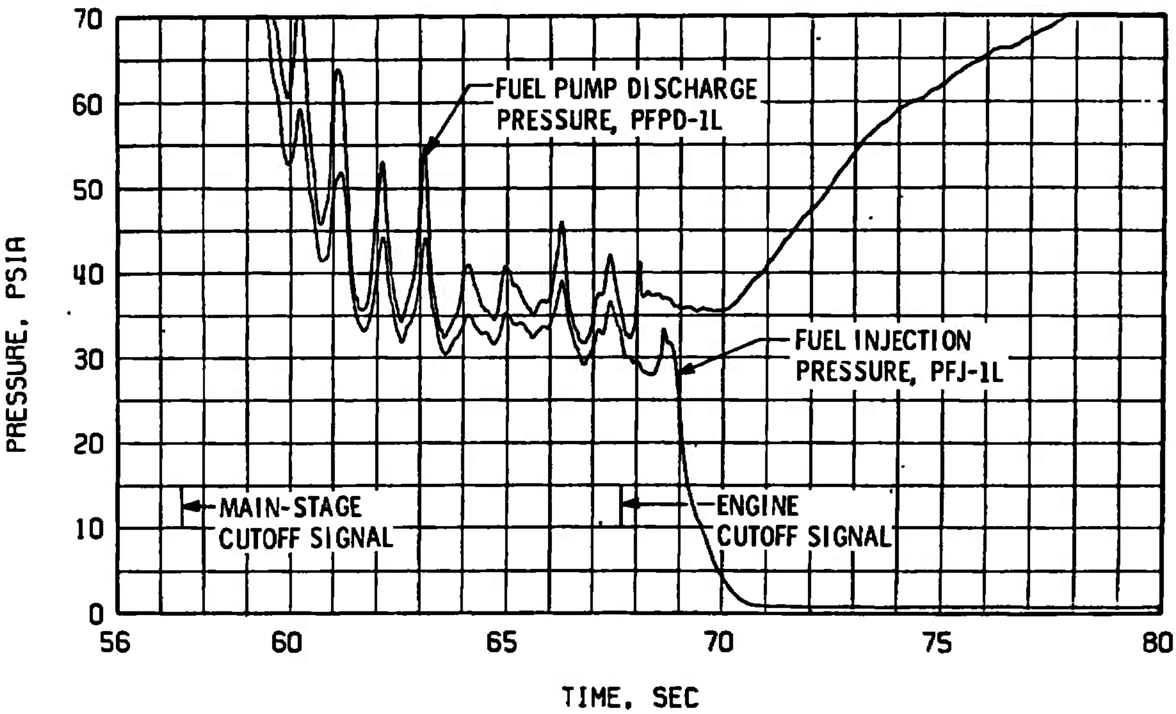


c. Post-Main-Stage Idle Mode

Fig. 17 Engine Ambient and Combustion Chamber Pressure, Firing 07A




a. Pre-Main-Stage Idle Mode




b. Post-Main-Stage Idle Mode

Fig. 18 Fuel Feed System Pressures, Firing 07A

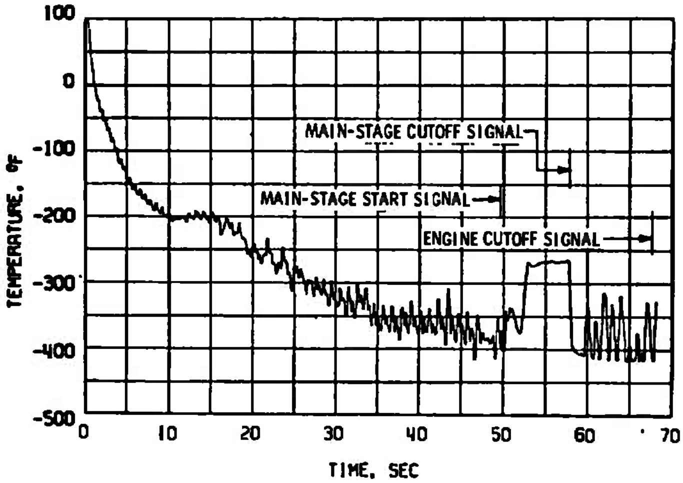



Fig. 19 Fuel Injection Temperature, Firing 07A

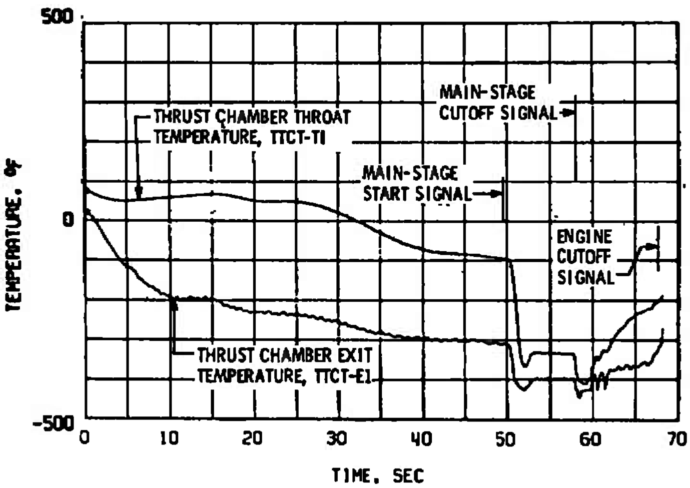



Fig. 20 Thrust Chamber External Skin Temperatures, Firing 07A

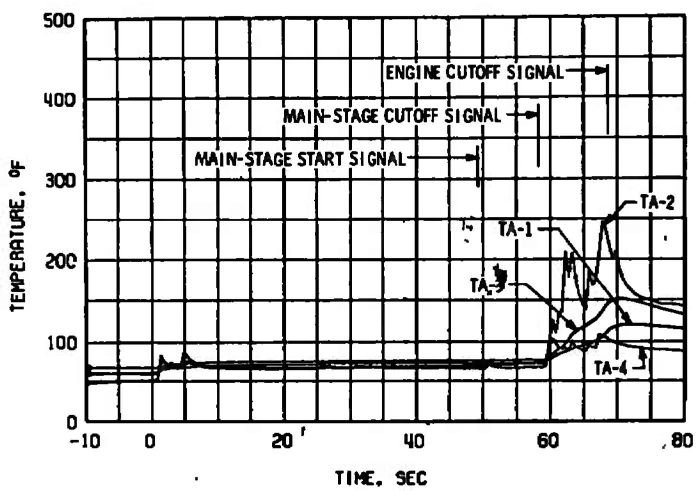
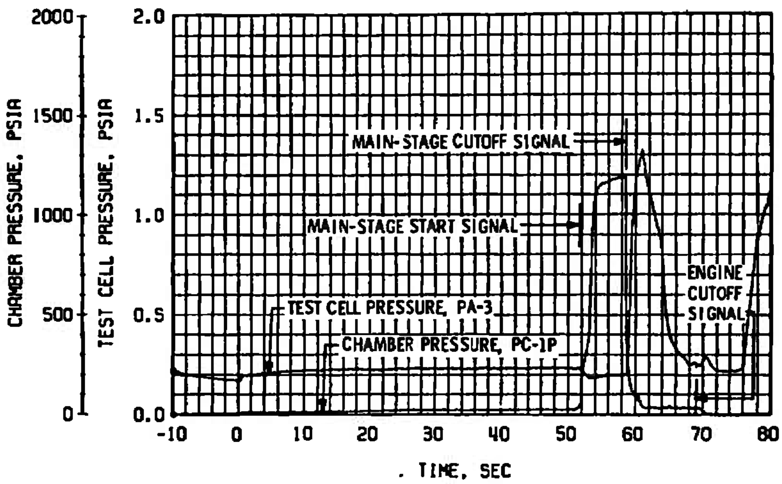
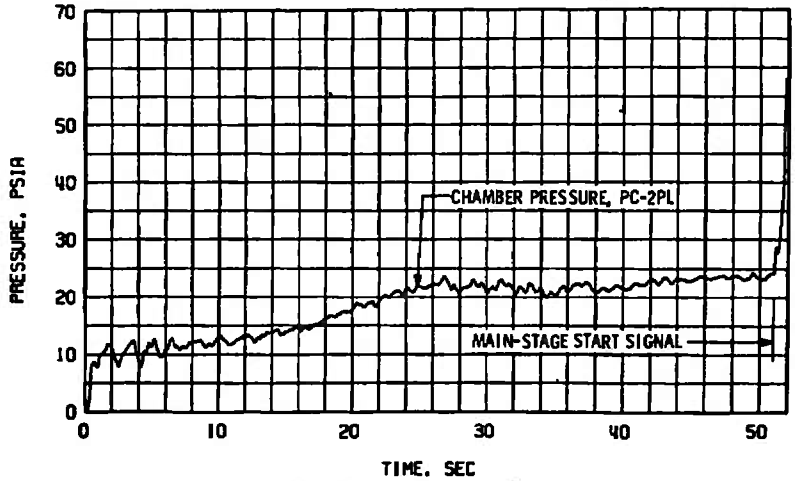


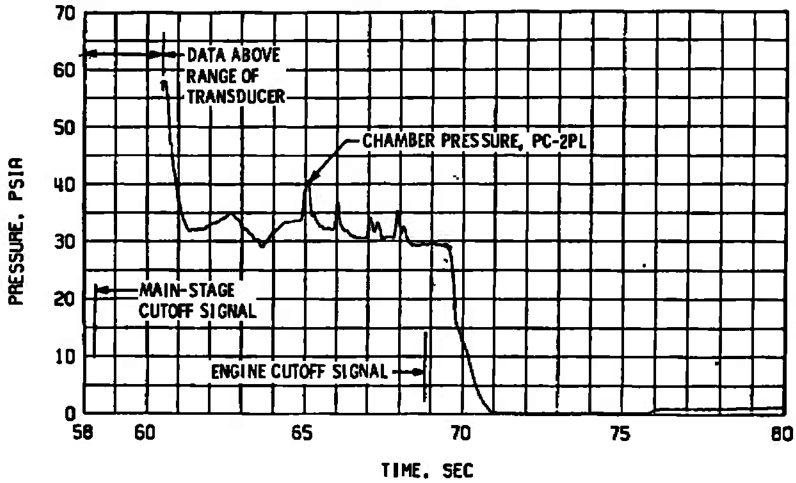

Fig. 21 Engine Ambient Temperature, Firing 07A




a. Total Duration of Firing

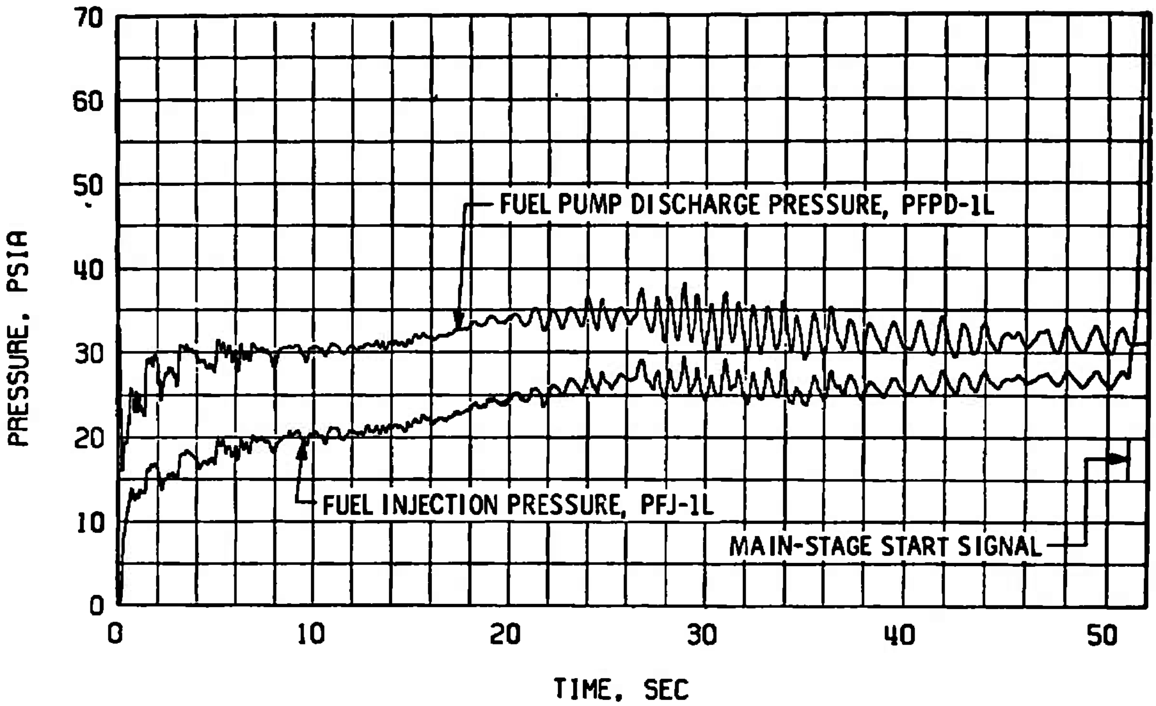



b. Pre-Main-Stage Idle Mode

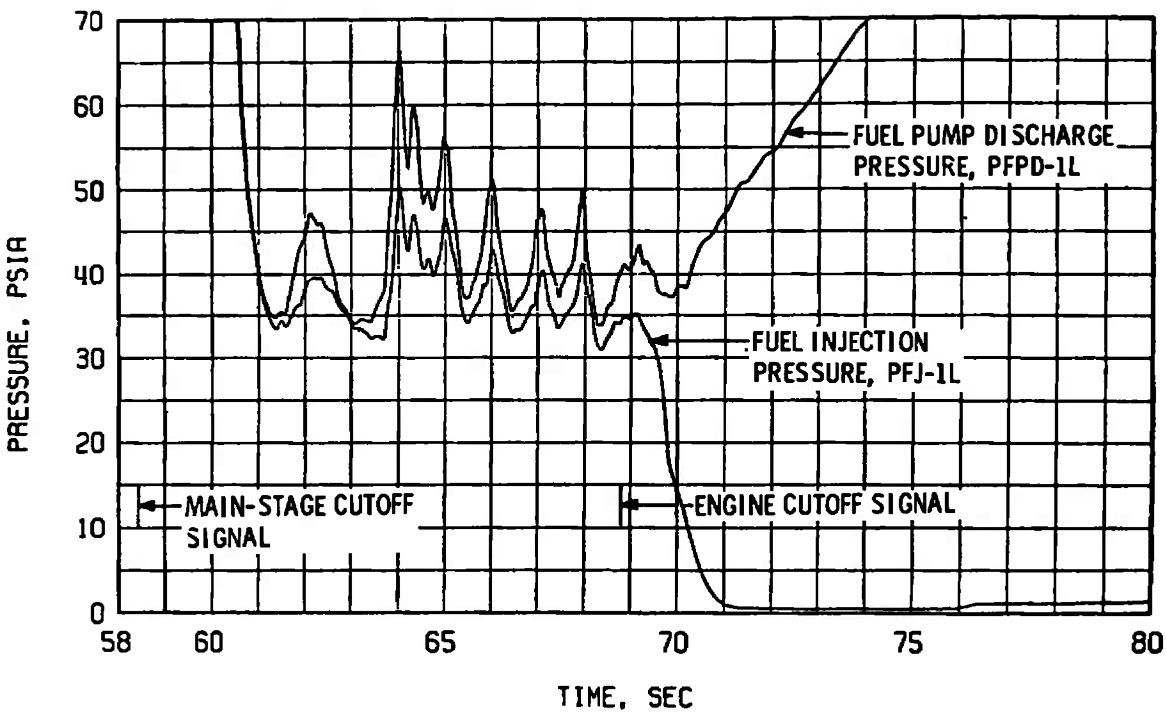



c. Post-Main-Stage Idle Mode

Fig. 22 Engine Ambient and Combustion Chamber Pressure, Firing 07B




a. Pre-Main-Stage Idle Mode




b. Post-Main-Stage Idle Mode

Fig. 23 Fuel Feed System Pressures, Firing 07B

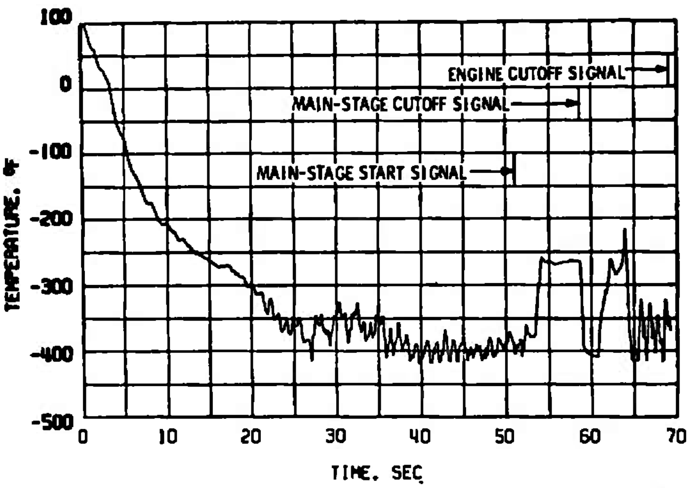



Fig. 24 Fuel Injection Temperature, Firing 07B

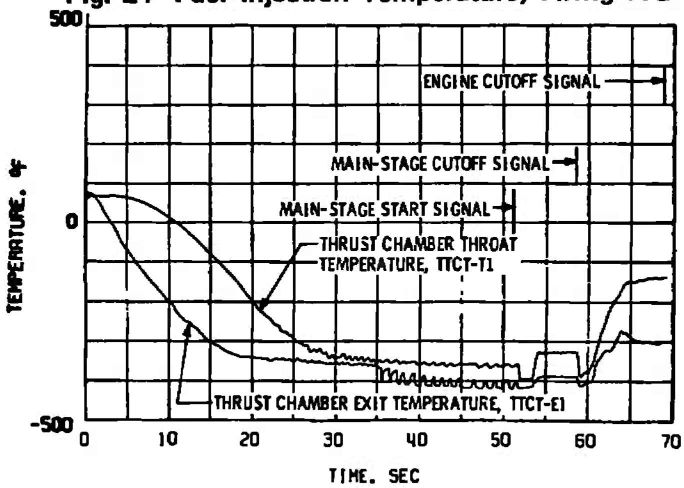



Fig. 25 Thrust Chamber External Skin Temperatures, Firing 07B

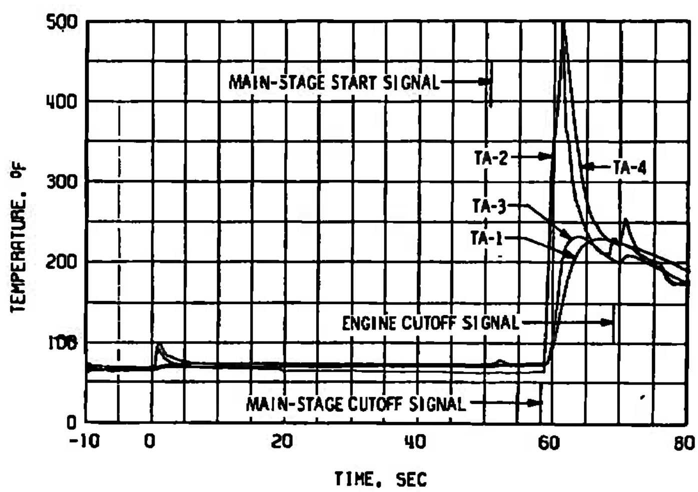
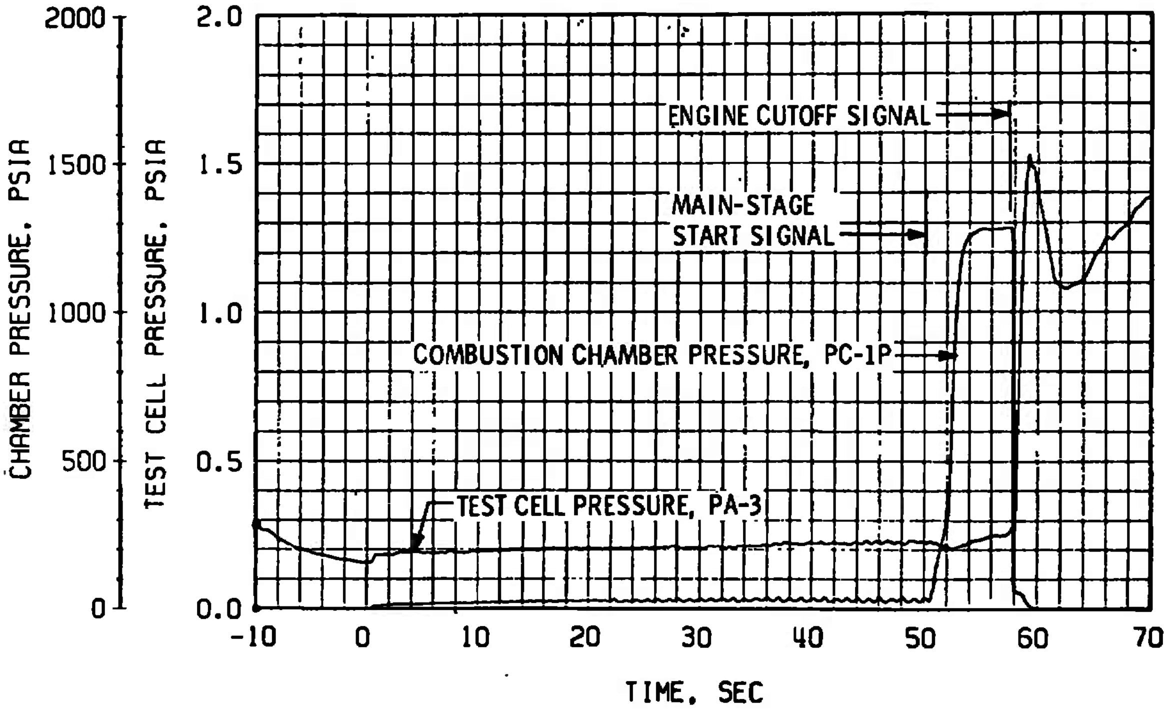
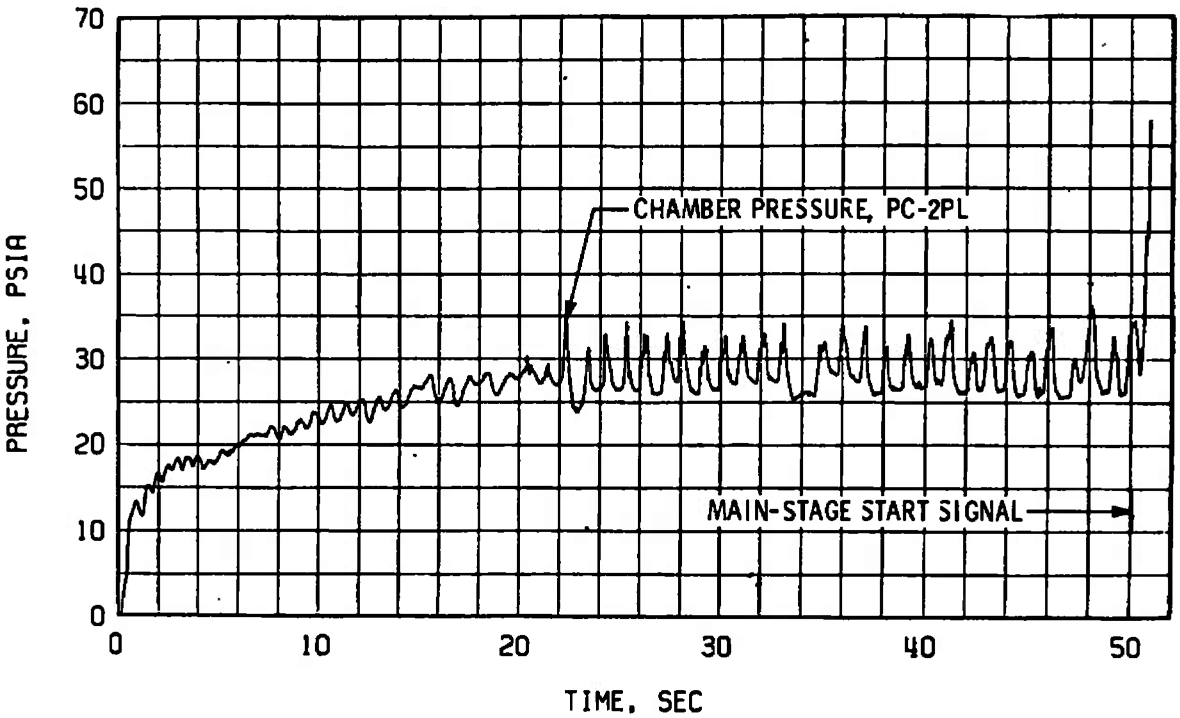



Fig. 26 Engine Ambient Temperature, Firing 07B




a. Total Duration of Firing




b. Pre-Main-Stage Idle Mode

Fig. 27 Engine Ambient and Combustion Chamber Pressure, Firing 07C

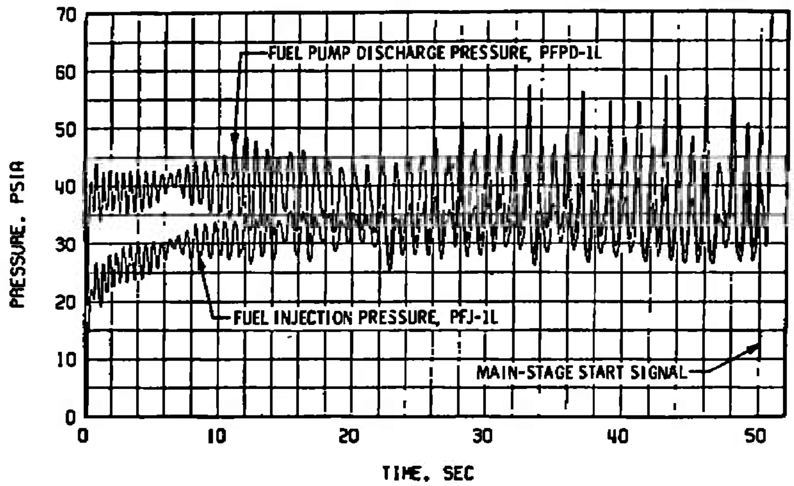



Fig. 28 Fuel Feed System Pressures, Firing 07C

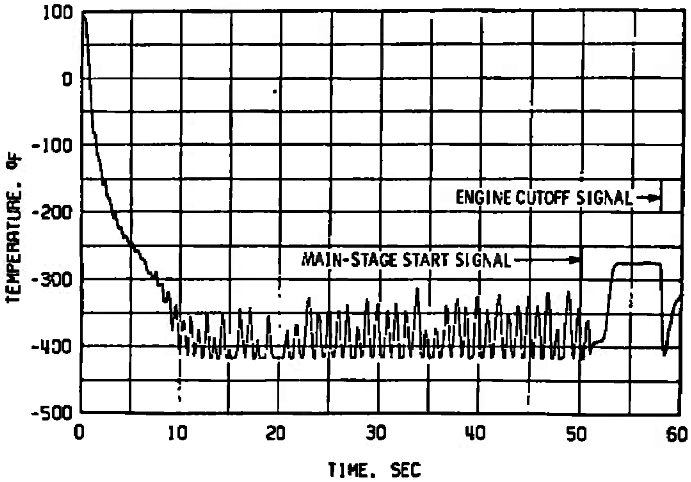



Fig. 29 Fuel Injection Temperature, Firing 07C

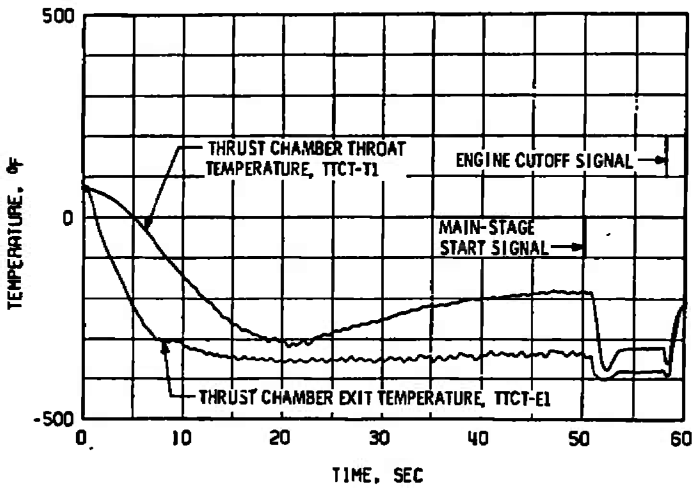



Fig. 30 Thrust Chamber External Skin Temperatures, Firing 07C

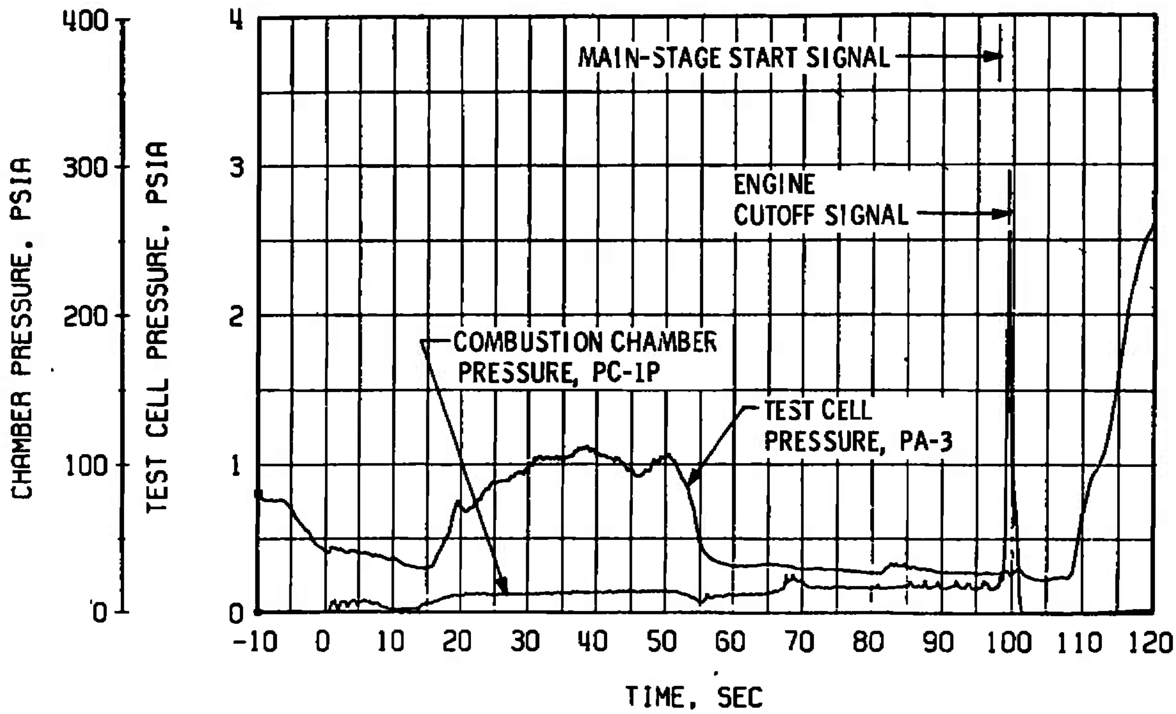



Fig. 31 Engine Ambient and Combustion Chamber Pressure, Firing 11A

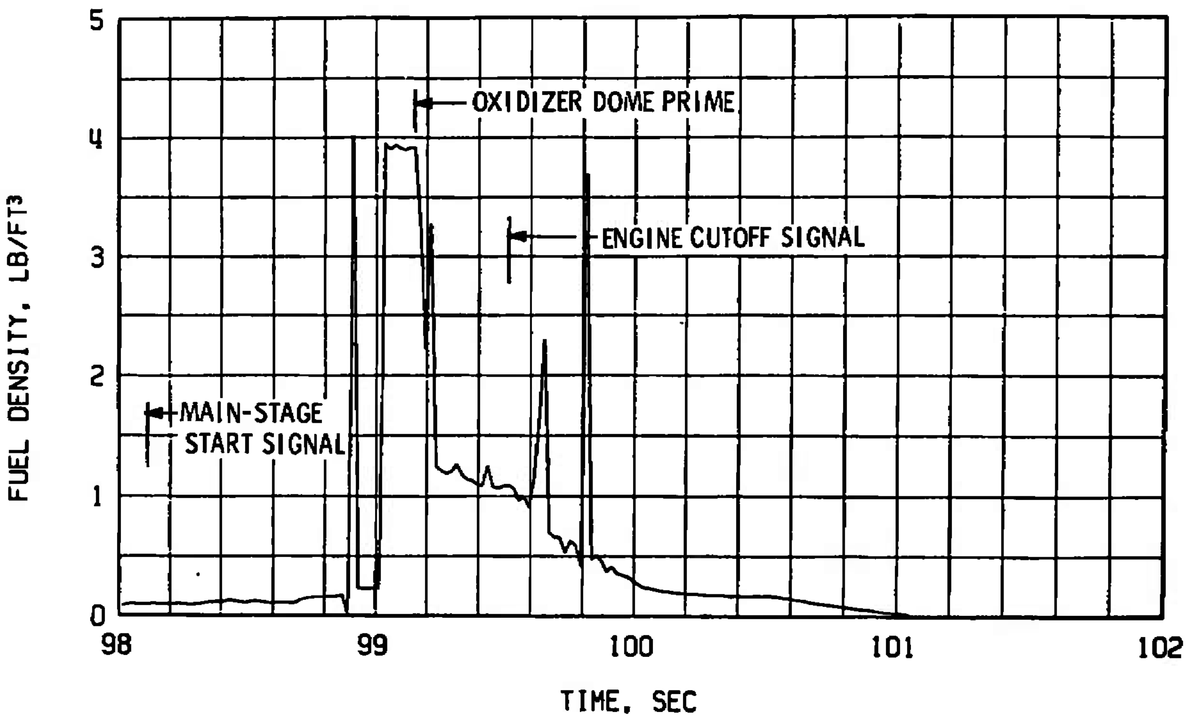



Fig. 32 Fuel Density at the Fuel Injector, Firing 11A

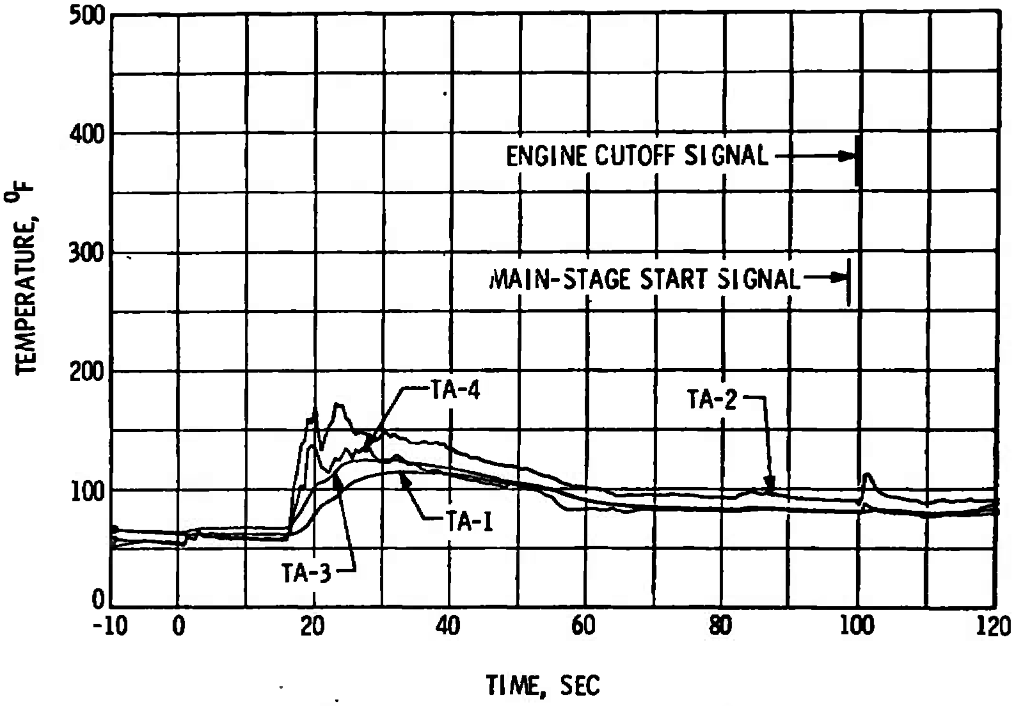



Fig. 33 Engine Ambient Temperature, Firing 11A

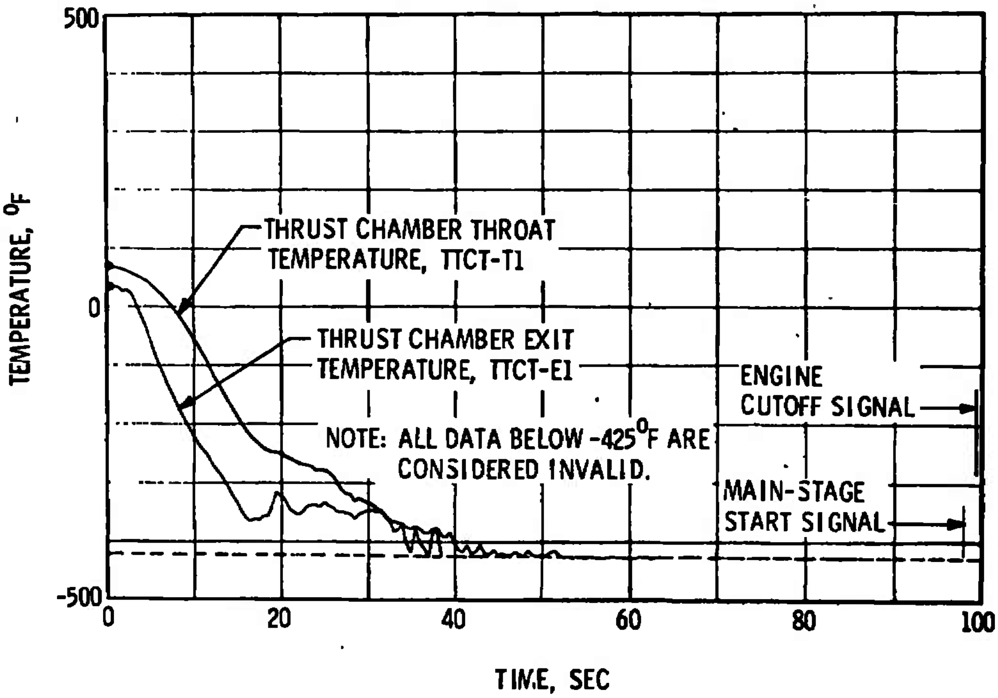
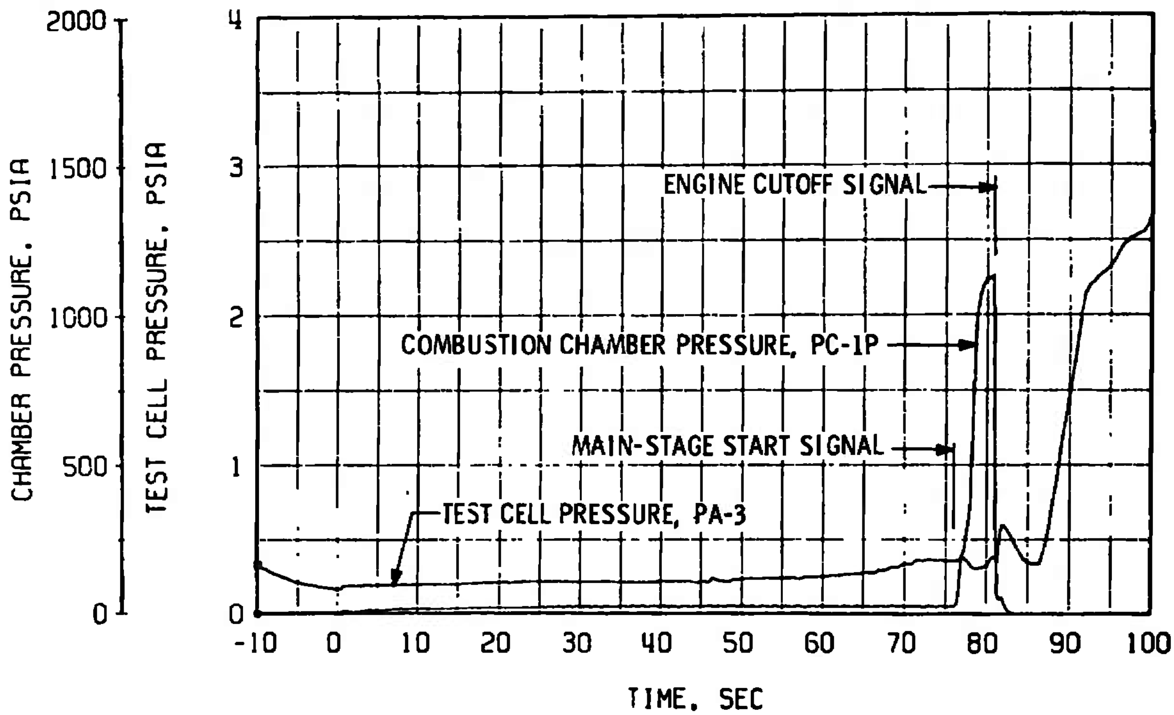
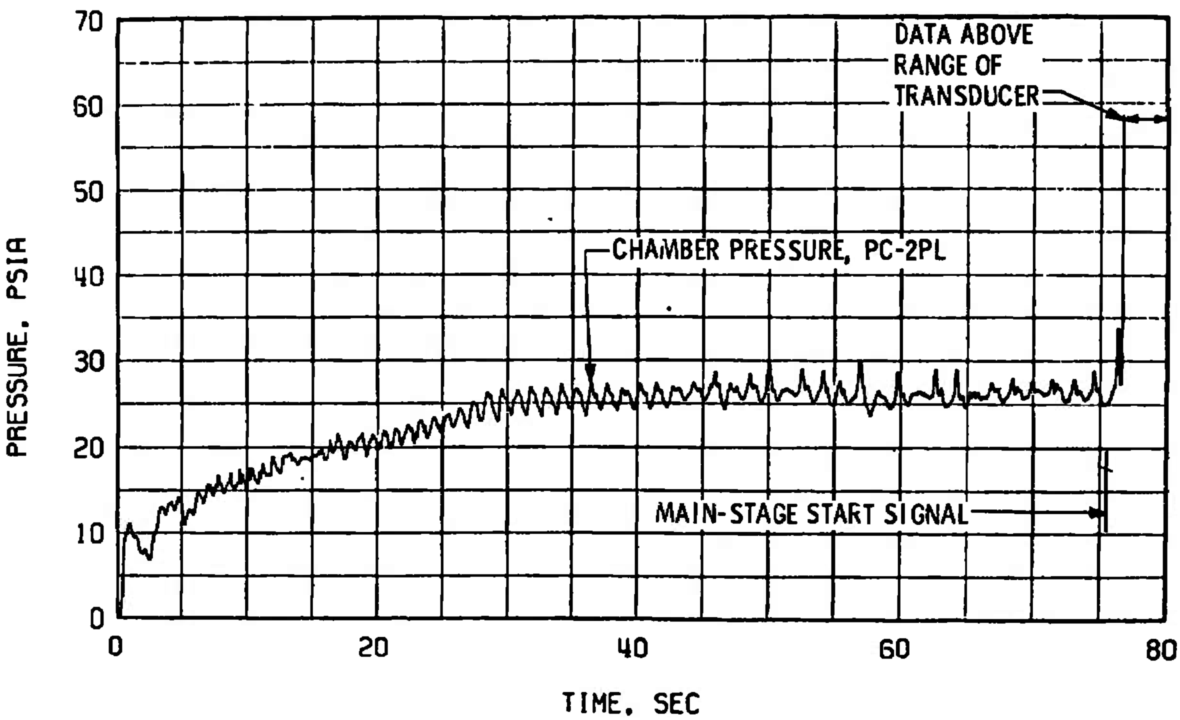



Fig. 34 Thrust Chamber External Skin Temperature, Firing 11A




a. Total Duration of Firing




b. Pre-Main-Stage Idle Mode

Fig. 35 Engine Ambient and Combustion Chamber Pressure, Firing 11B

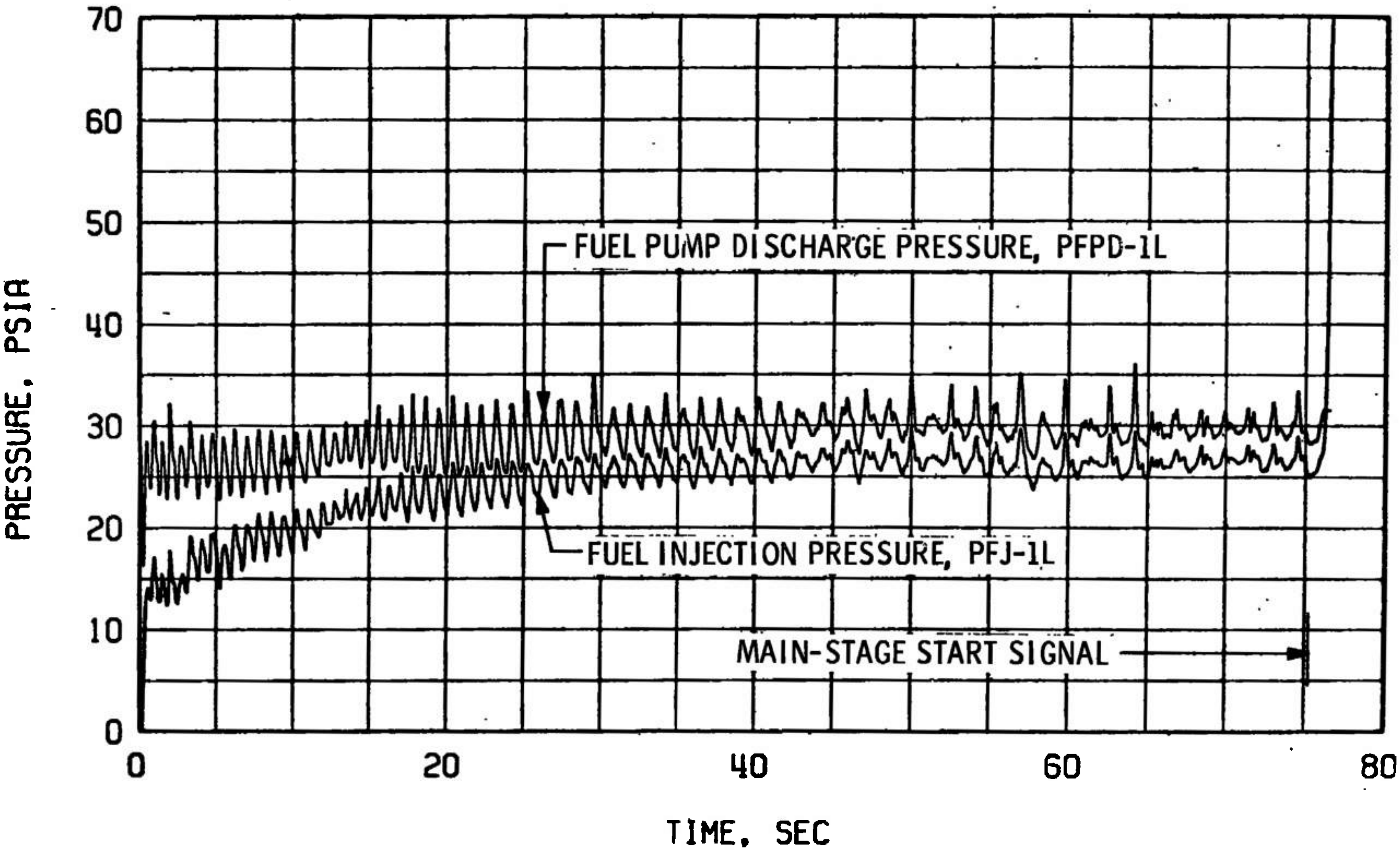
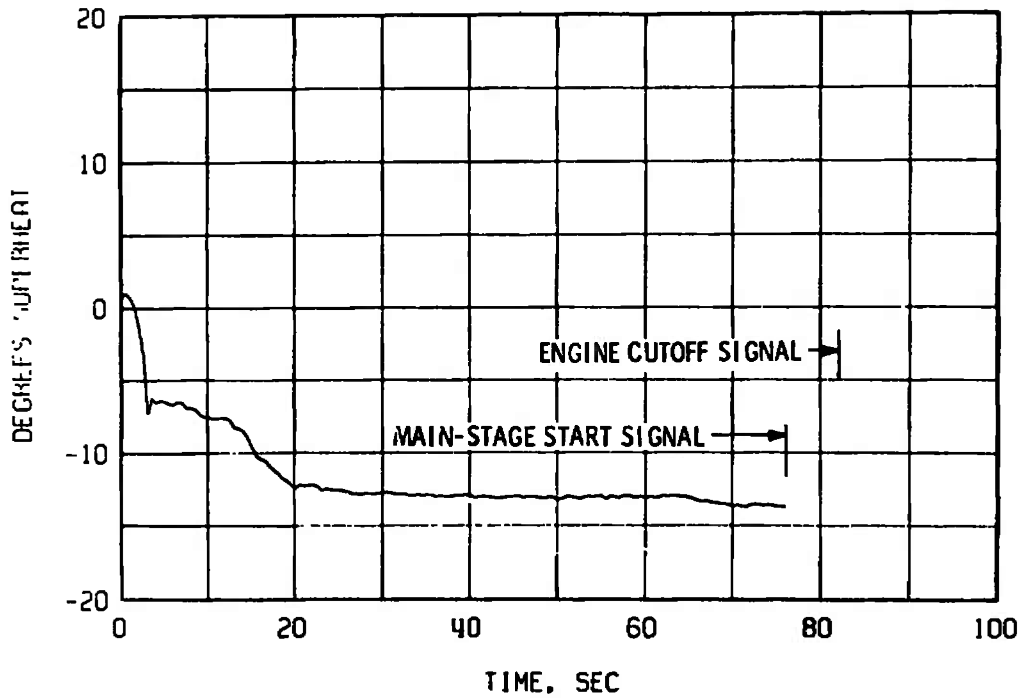
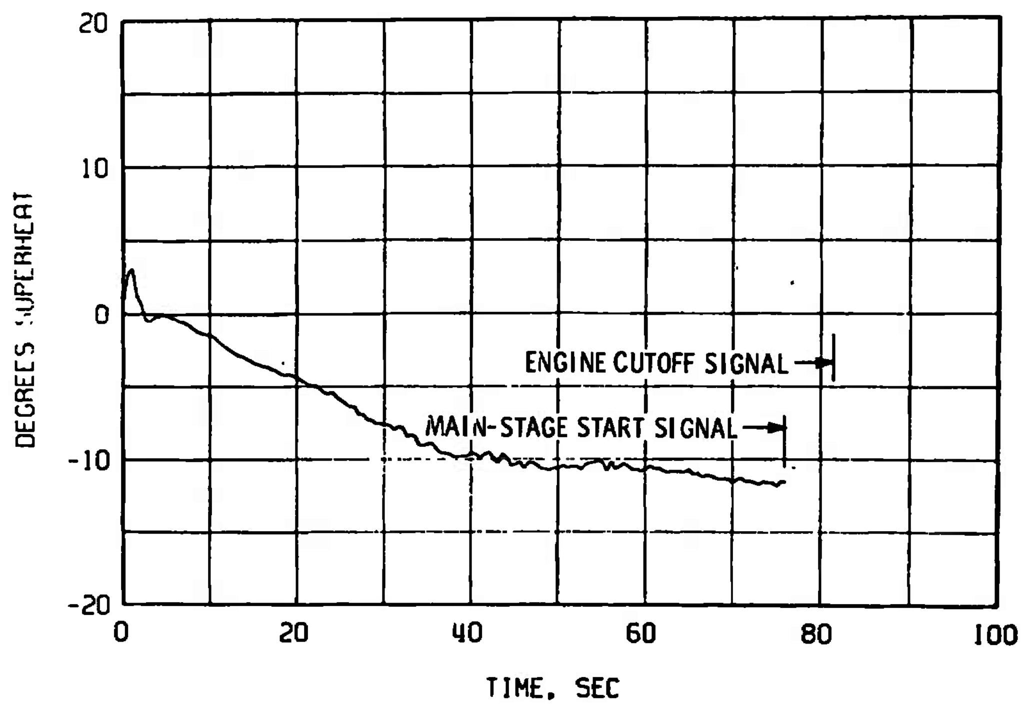



Fig. 36 Fuel Feed System Pressures, Firing 11B

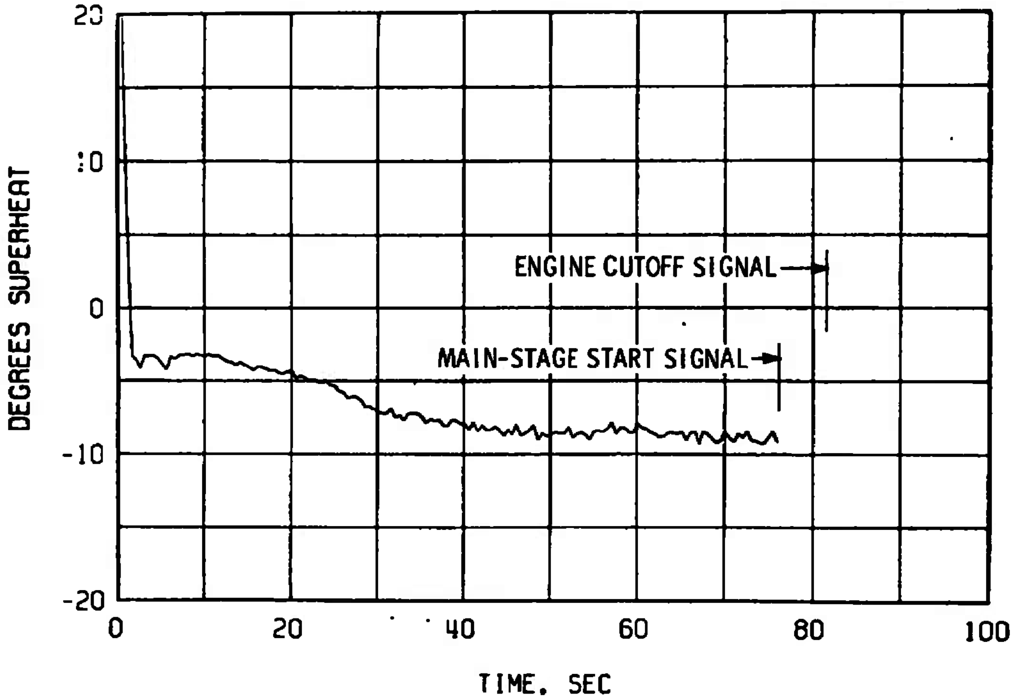



a. Oxidizer Pump Inlet

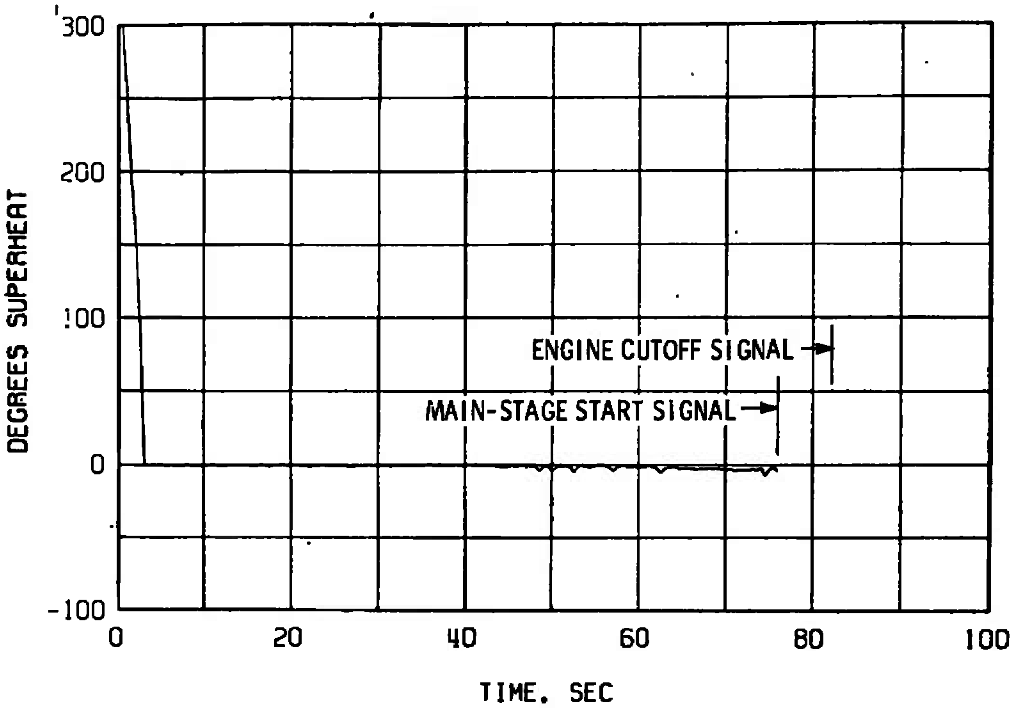



b. Oxidizer Pump Discharge

Fig. 37 Propellant Feed System Conditions during Idle Mode, Firing 11B

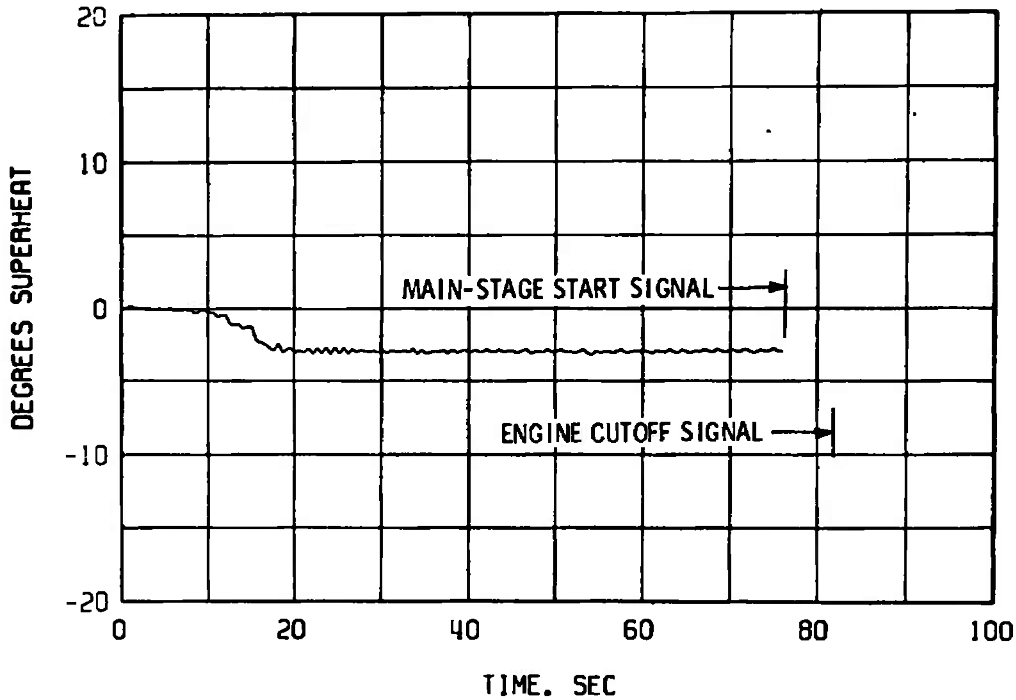



c. Oxidizer Idle-Mode Supply Line

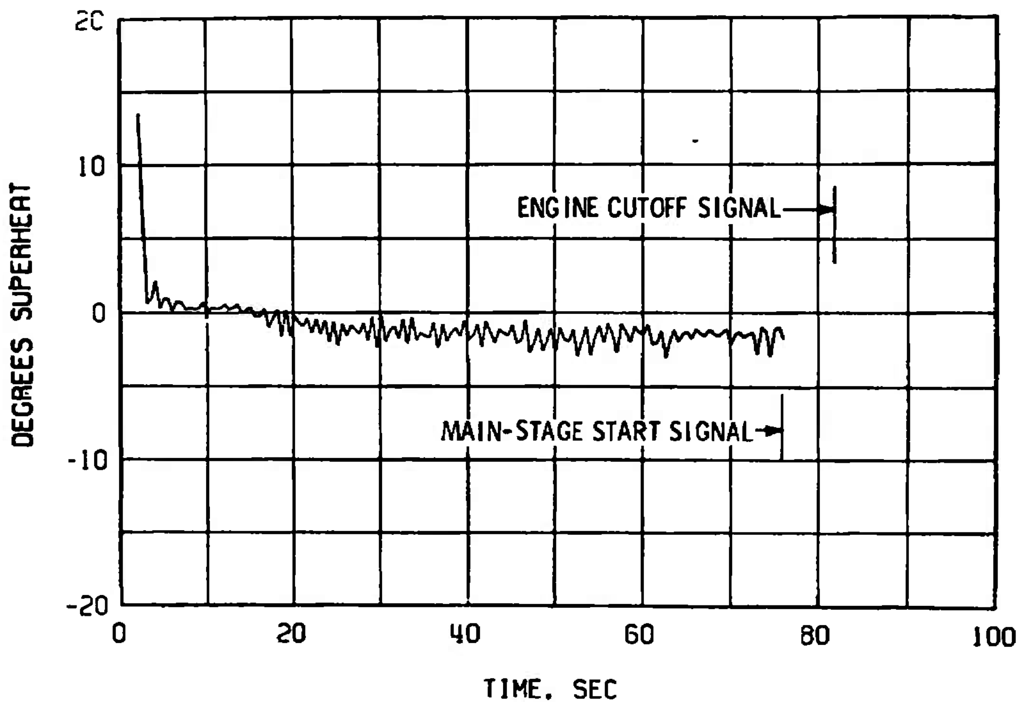



d. Oxidizer Injector

Fig. 37 Continued

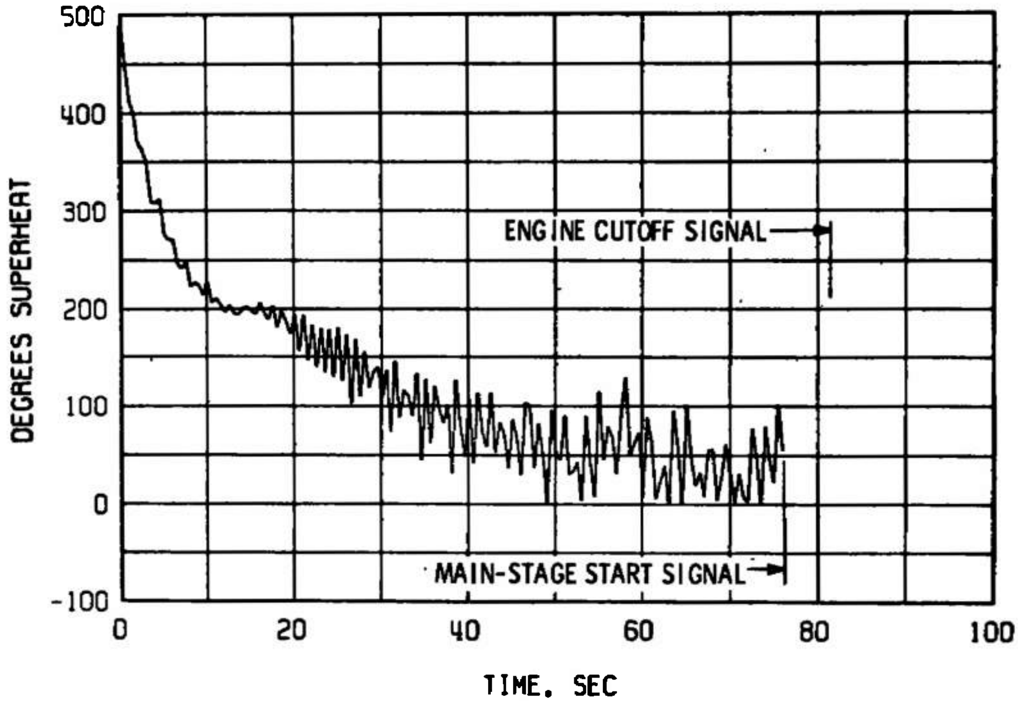



e. Fuel Pump Inlet




f. Fuel Pump Discharge

Fig. 37 Continued




g. Fuel Injector
Fig. 37 Concluded

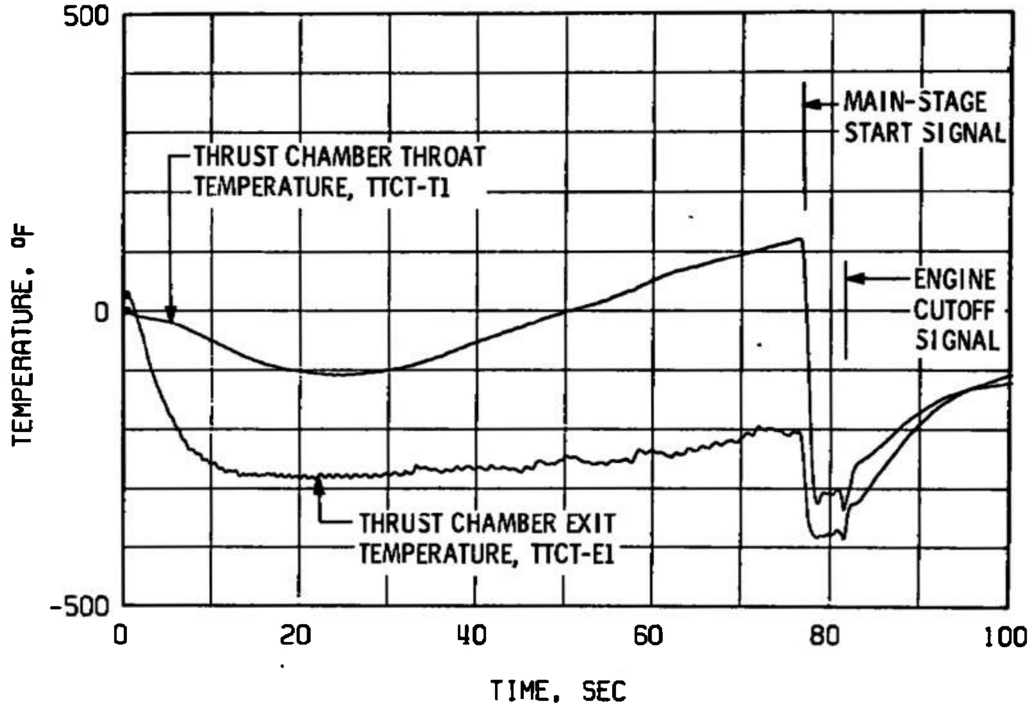
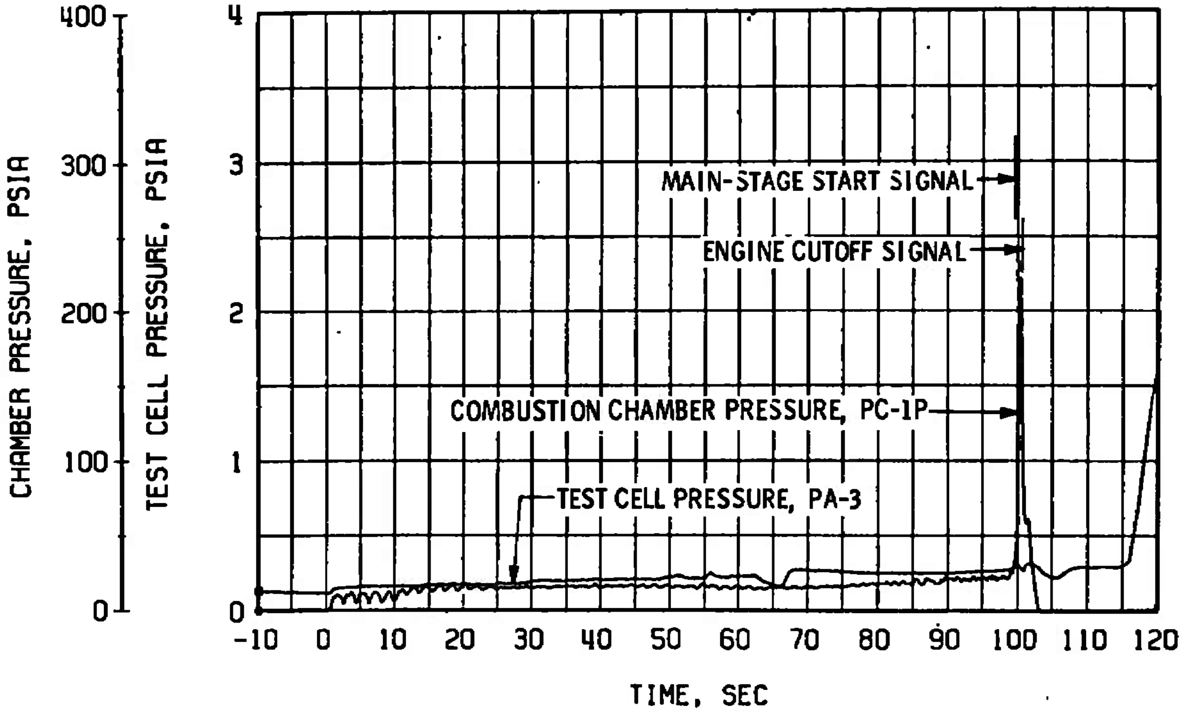
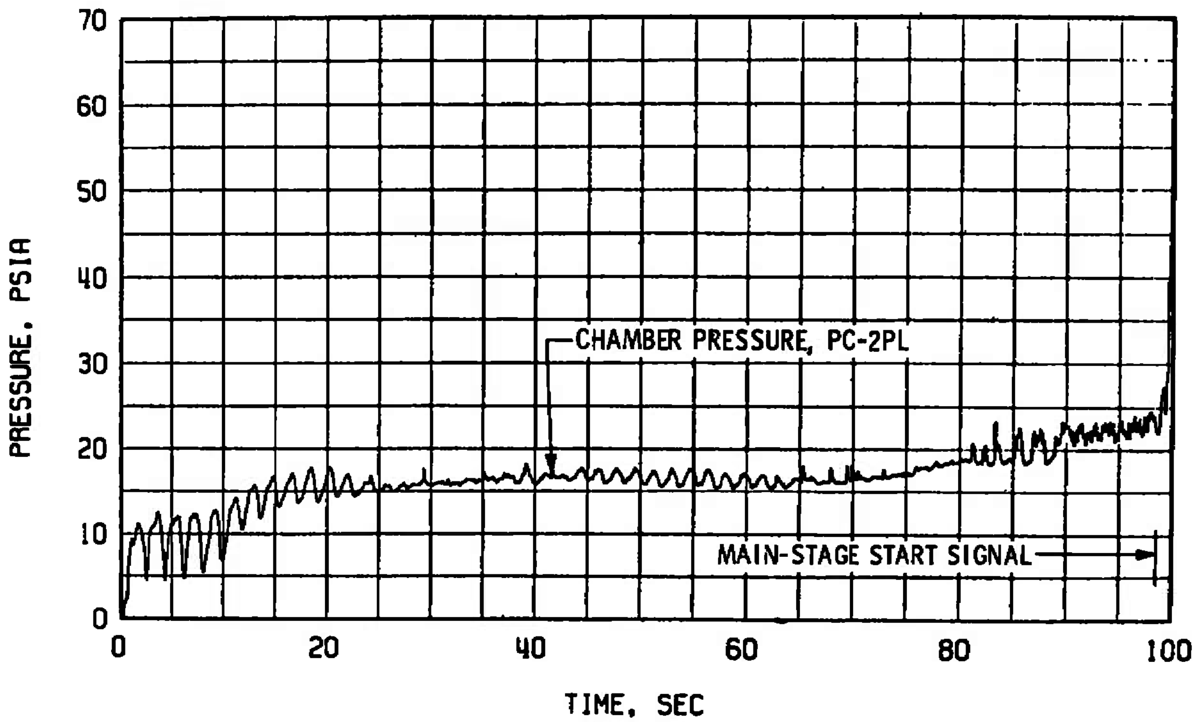



Fig. 38 Thrust Chamber External Skin Temperatures, Firing 11B




a. Total Duration of Firing




b. Pre-Main-Stage Idle Mode

Fig. 39 Engine Ambient and Combustion Chamber Pressure, Firing 11C

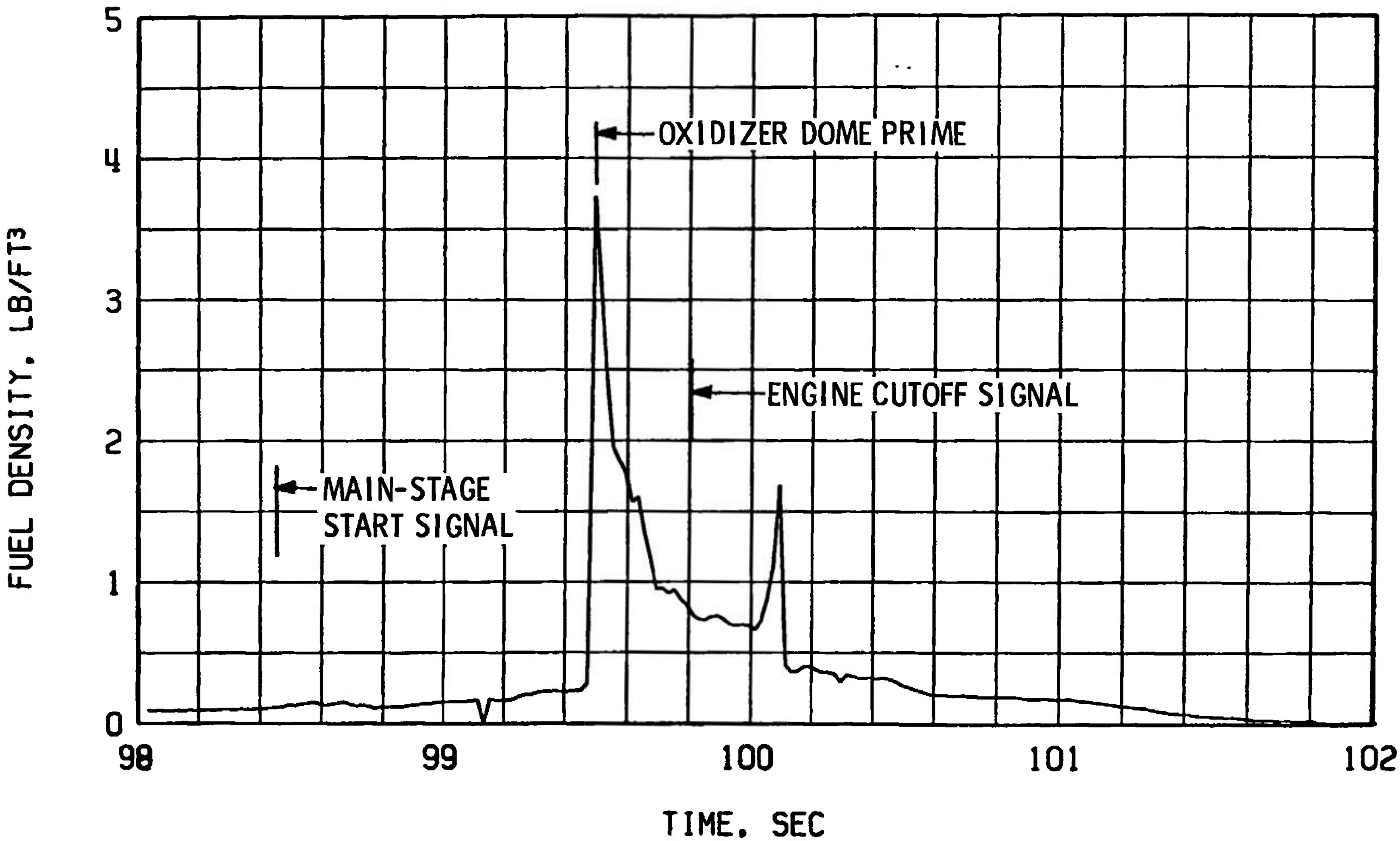
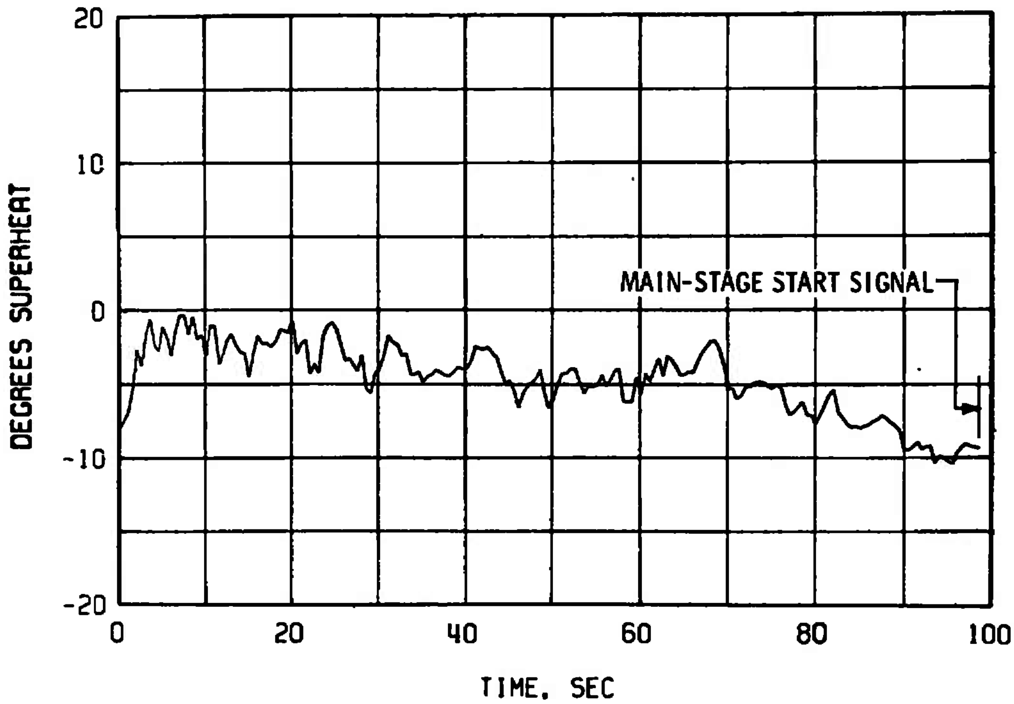
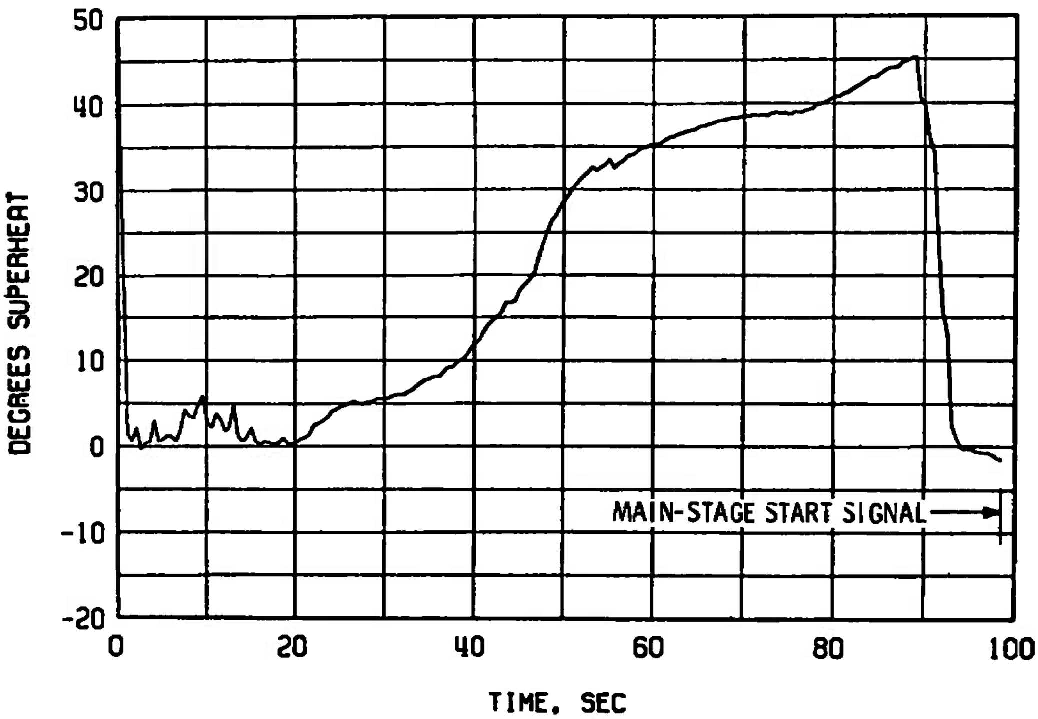



Fig. 40 Fuel Density at the Fuel Injector, Firing 11C

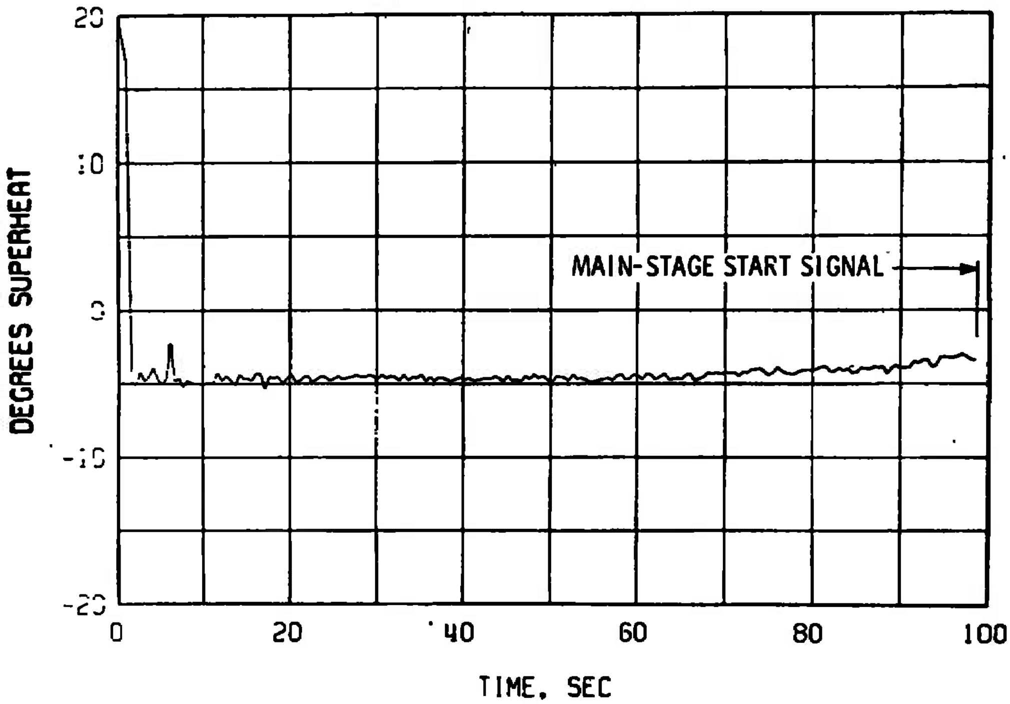



a. Oxidizer Pump Inlet

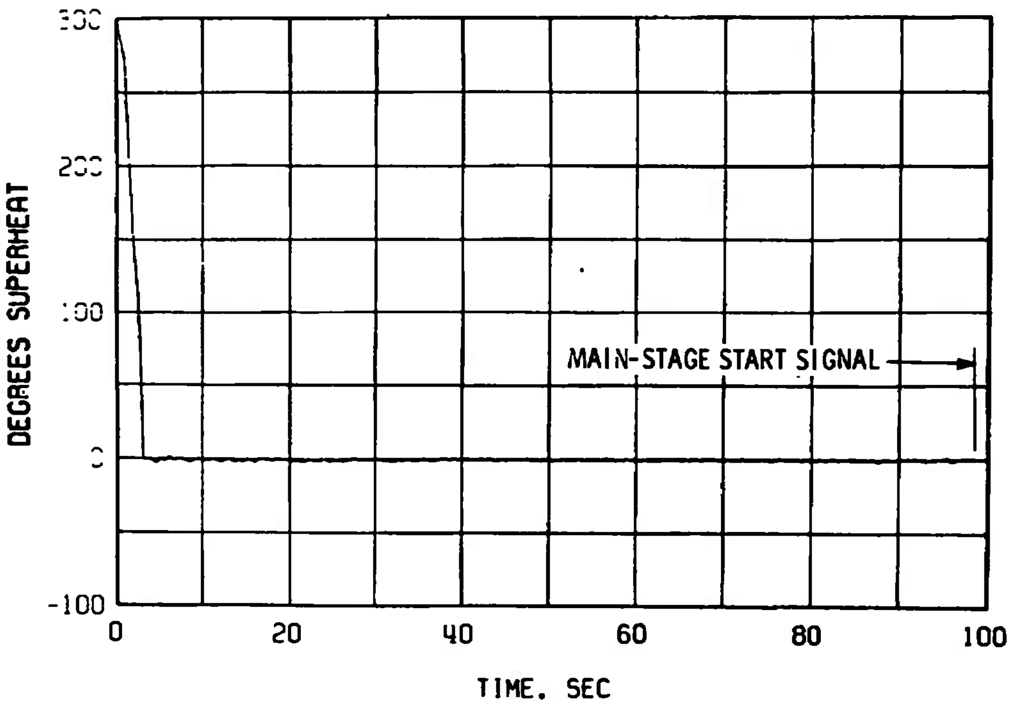



b. Oxidizer Pump Discharge

Fig. 41 Propellant Feed System Conditions during Idle Mode, Firing 11C

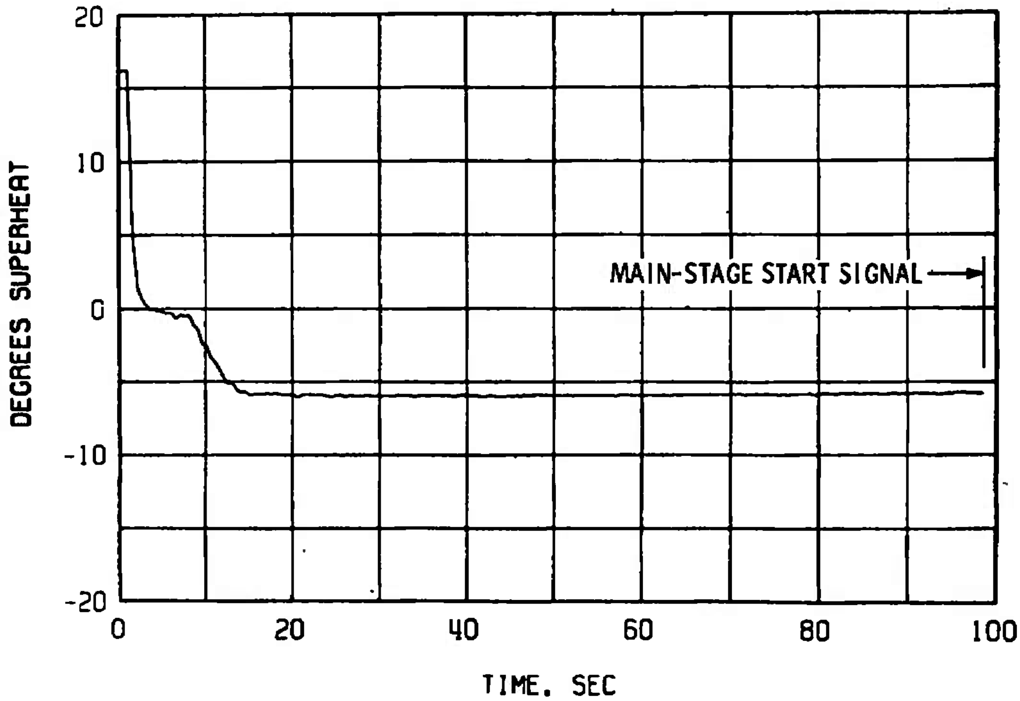



c. Oxidizer Idle-Mode Supply Line

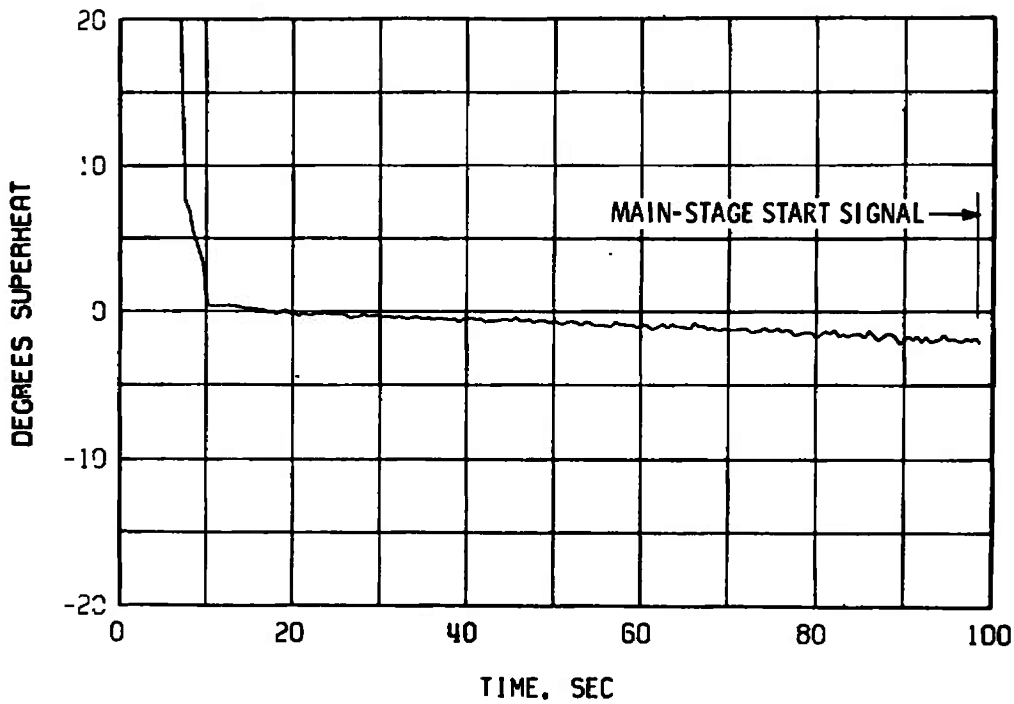



d. Oxidizer Injector

Fig. 41 Continued

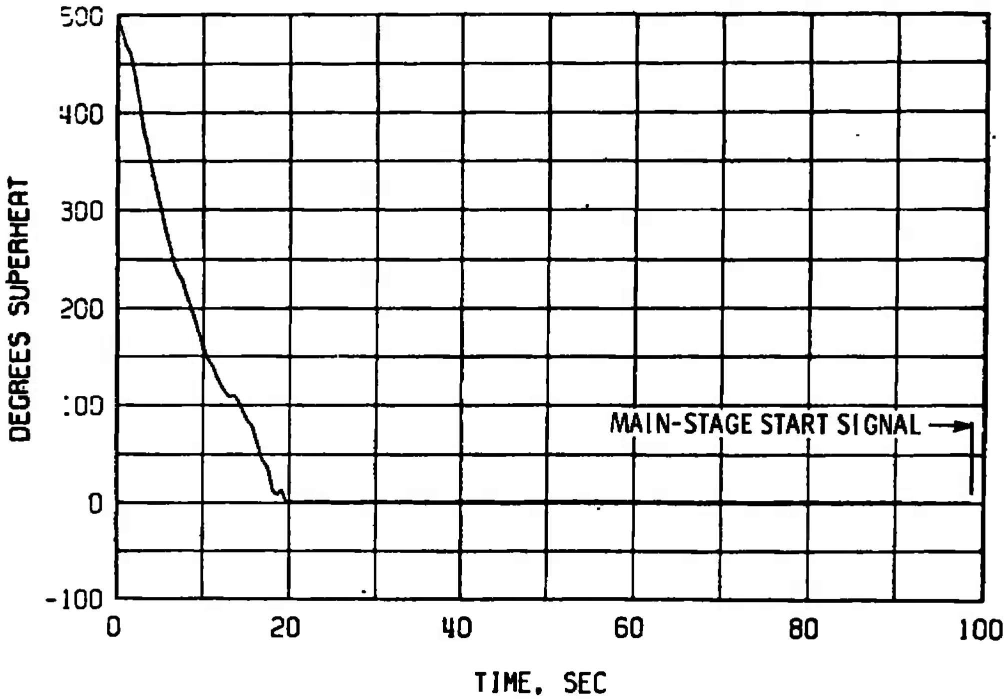



e. Fuel Pump Inlet




f. Fuel Pump Discharge

Fig. 41 Continued




g. Fuel Injector

Fig. 41 Concluded

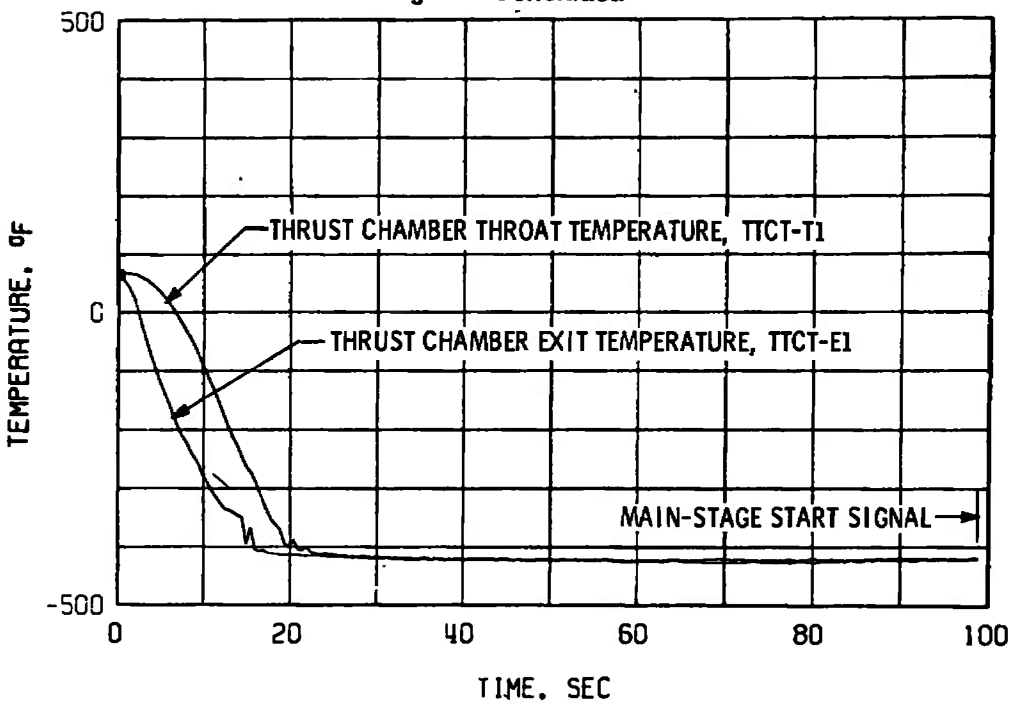



Fig. 42 Thrust Chamber External Skin Temperature, Firing 11C

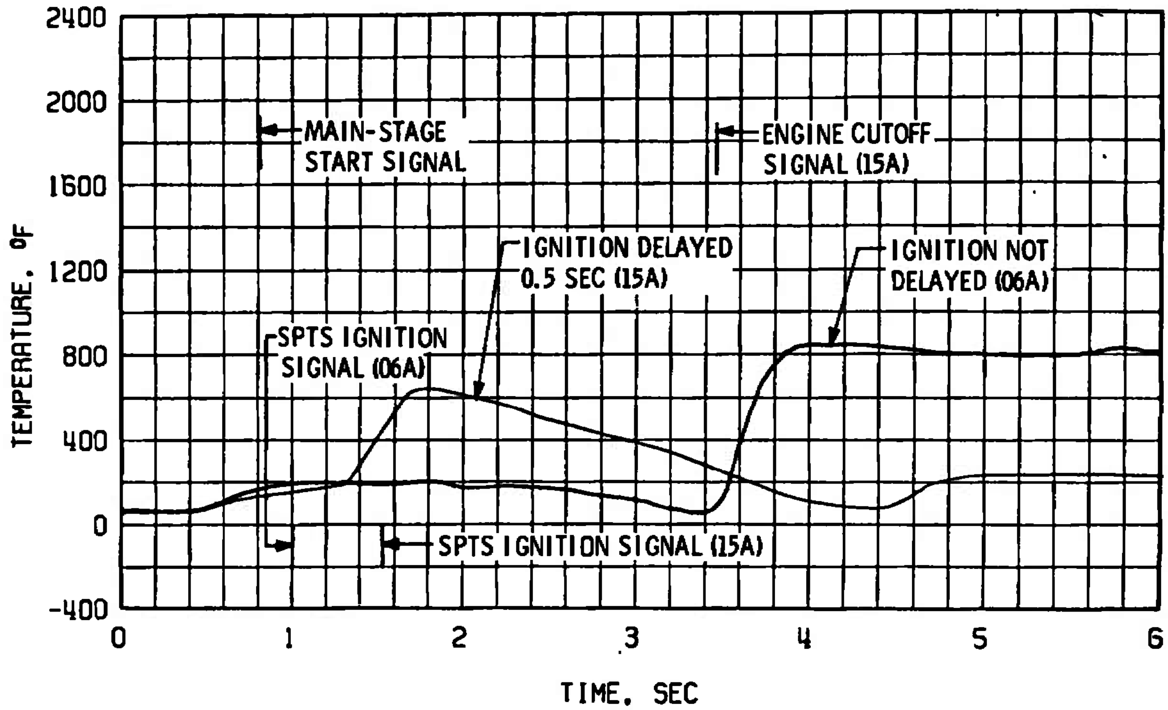



Fig. 43 Hot Gas Tapoff Manifold Temperature

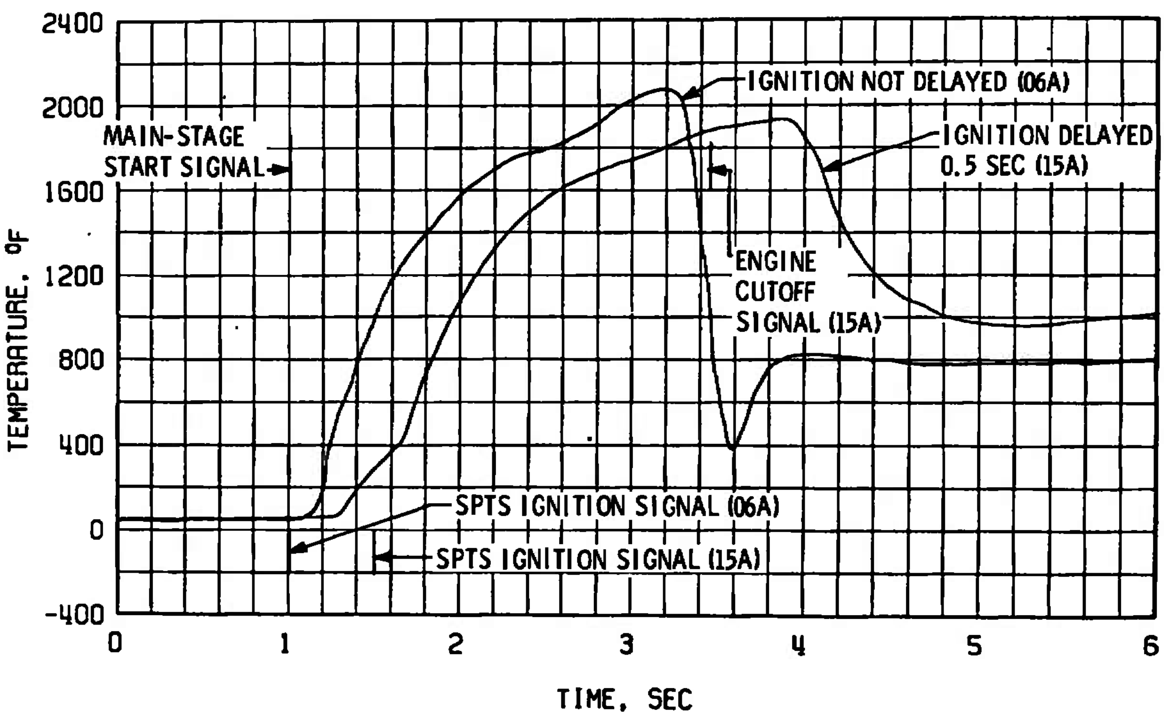



Fig. 44 Fuel Turbine Inlet Temperature

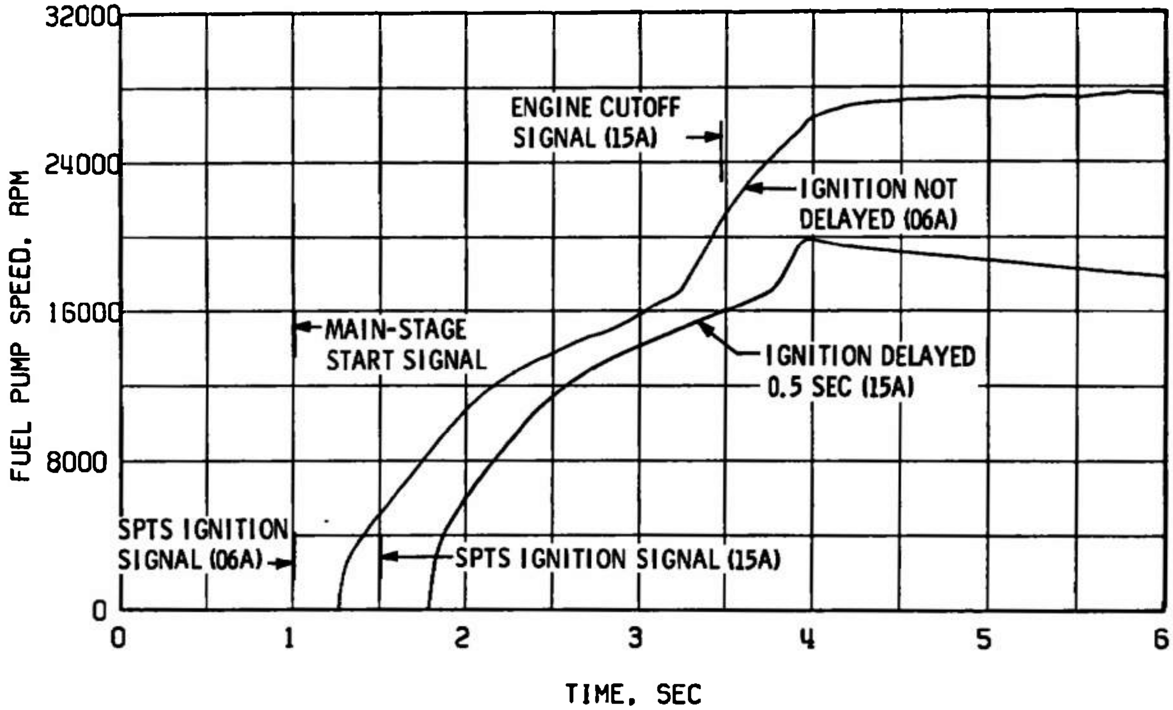



Fig. 45 Fuel Turbine Speed

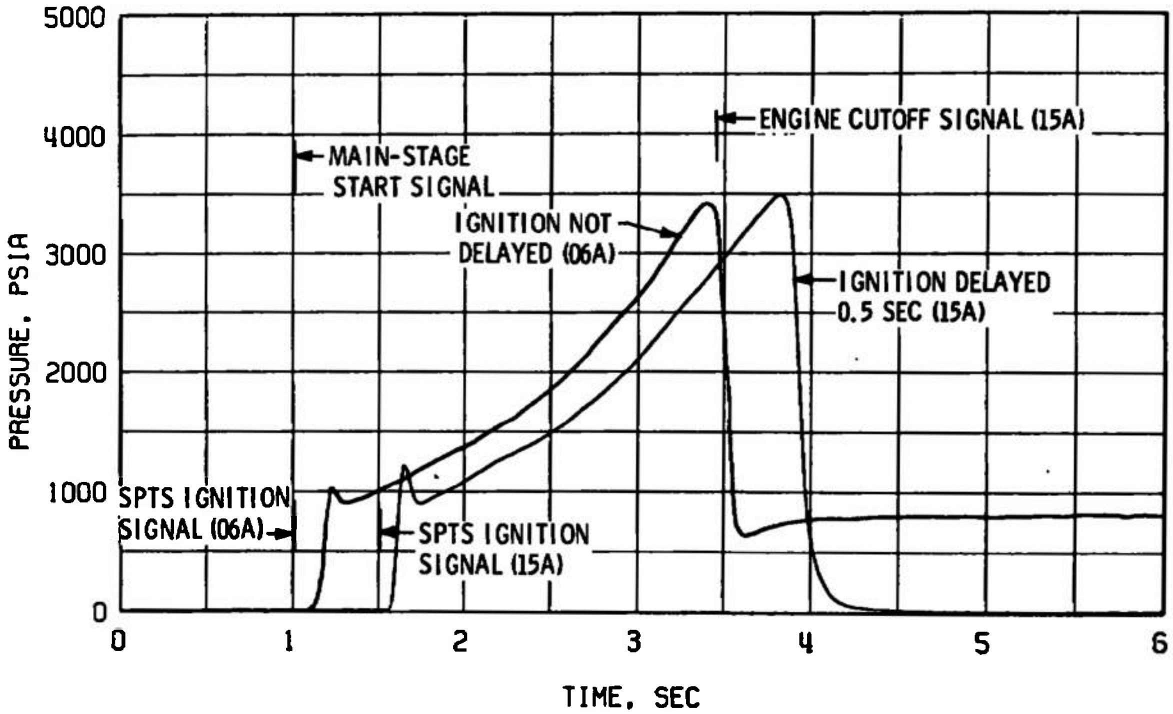



Fig. 46 Solid-Propellant Turbine Starter Chamber Pressure

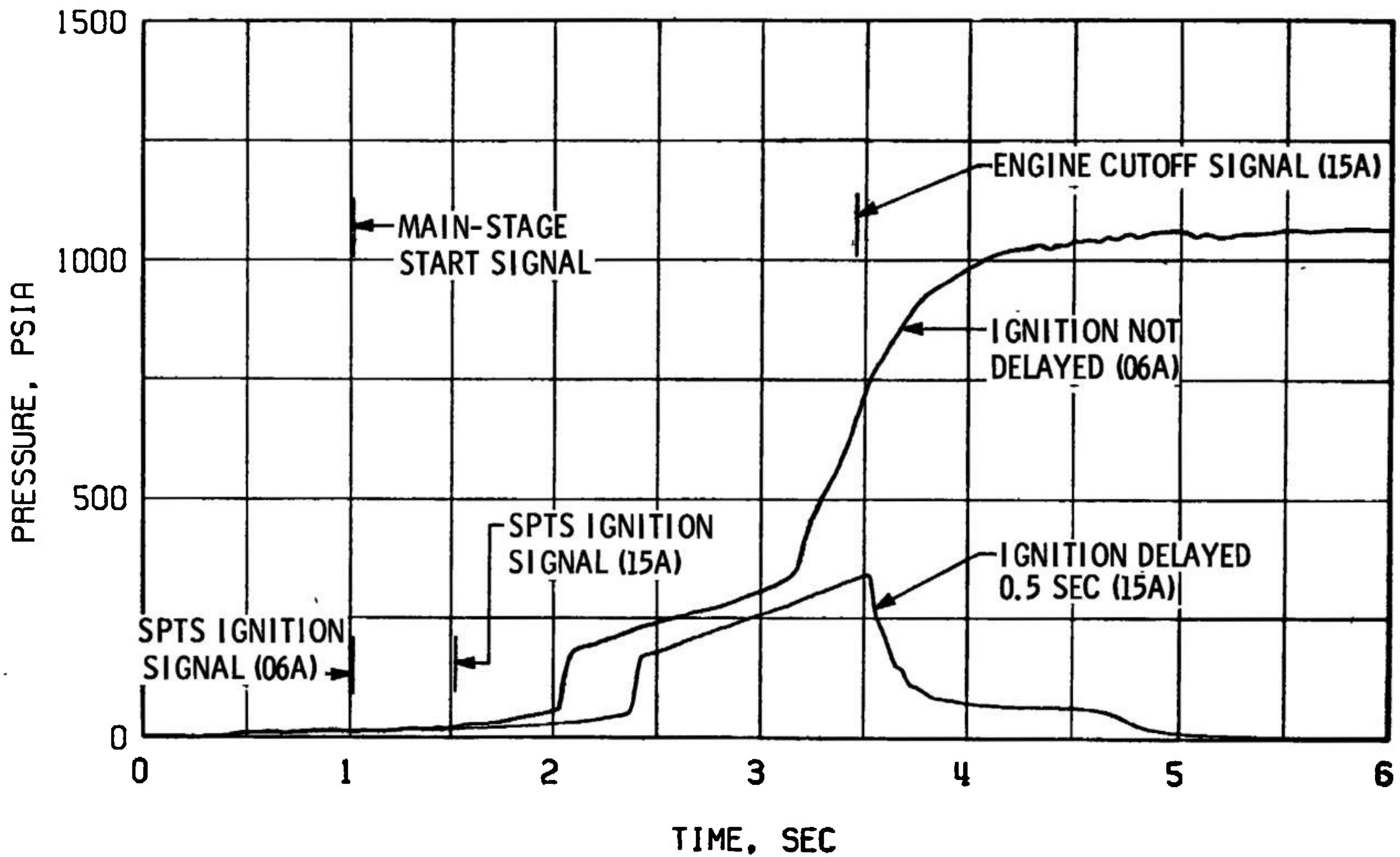



Fig. 47 Engine Combustion Chamber Pressure, PC-1P

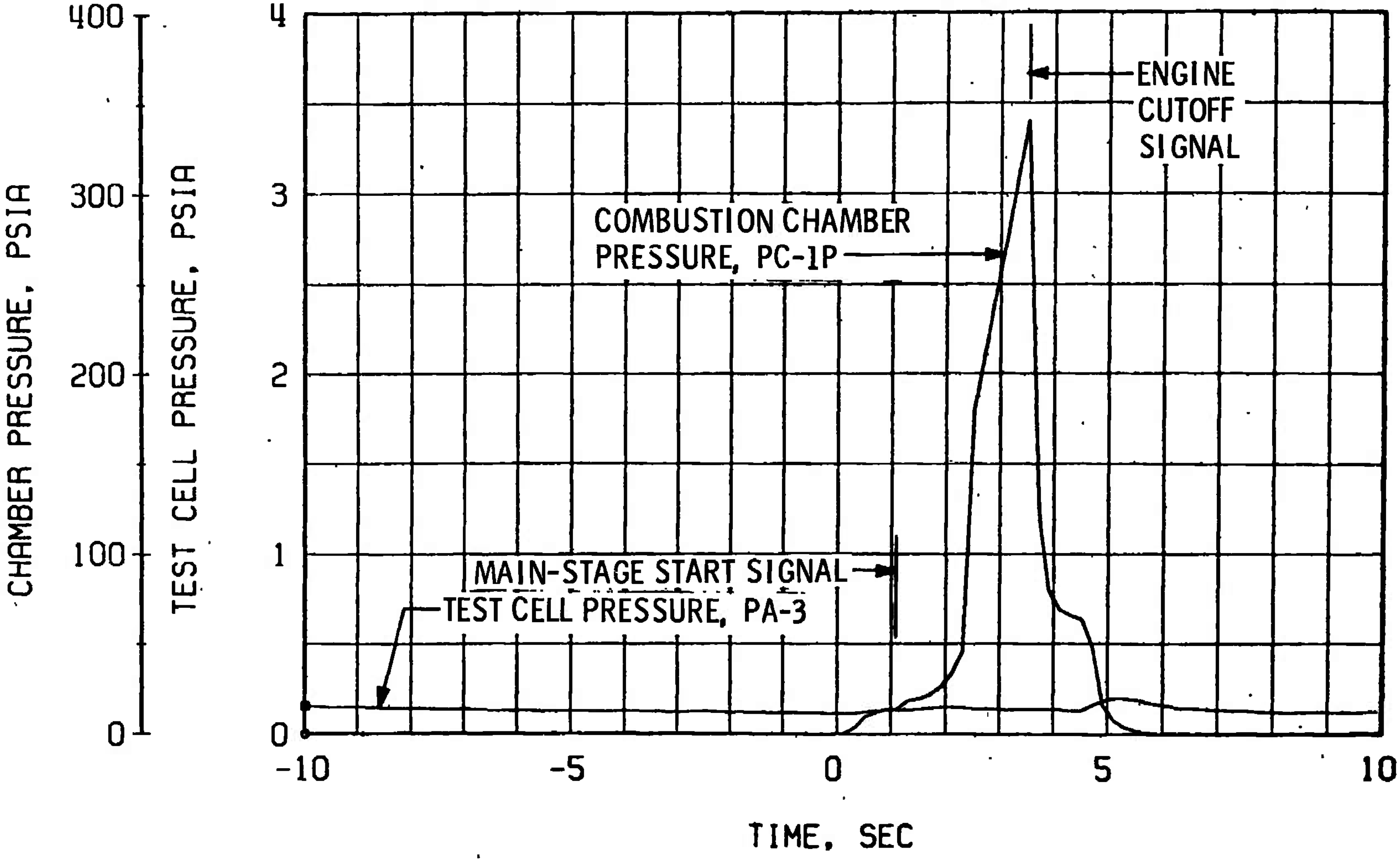



Fig. 48 Engine Ambient and Combustion Chamber Pressure, Firing 15A

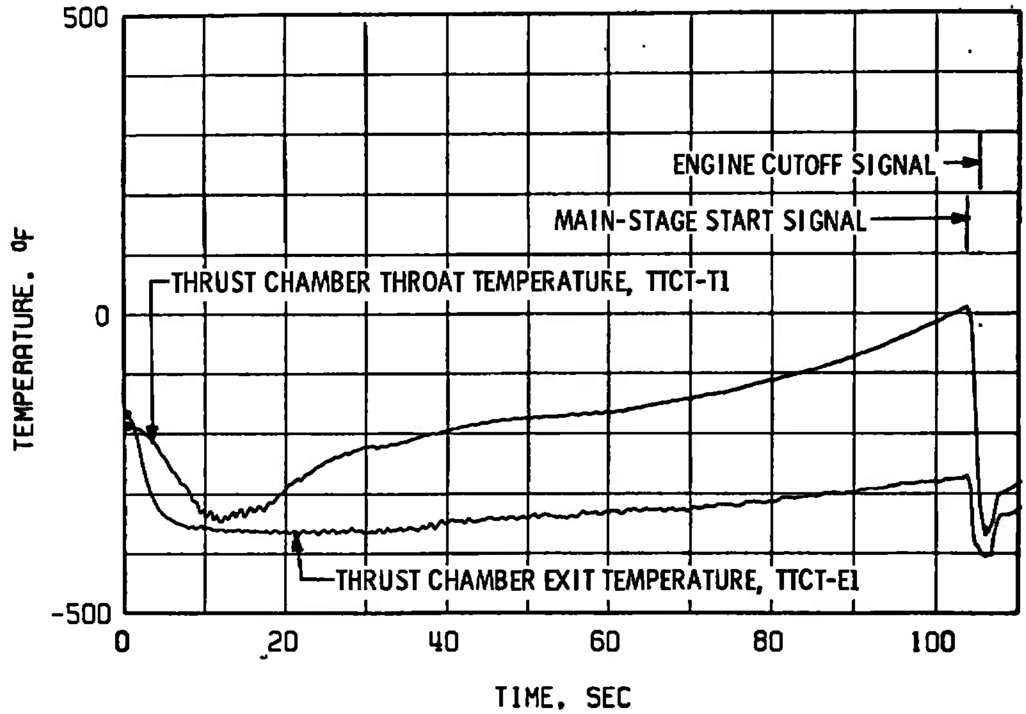



Fig. 49 Thrust Chamber Throat External Skin Temperature, Firing 15B

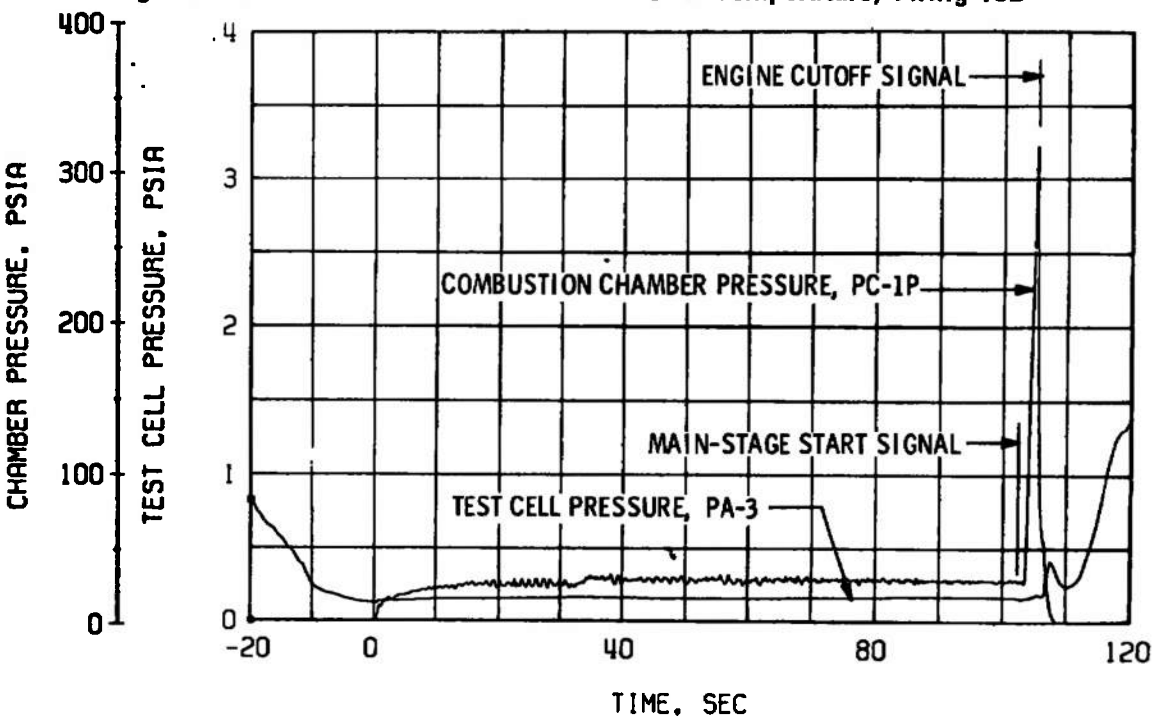



Fig. 50 Engine Ambient and Combustion Chamber Pressure, Firing 15B

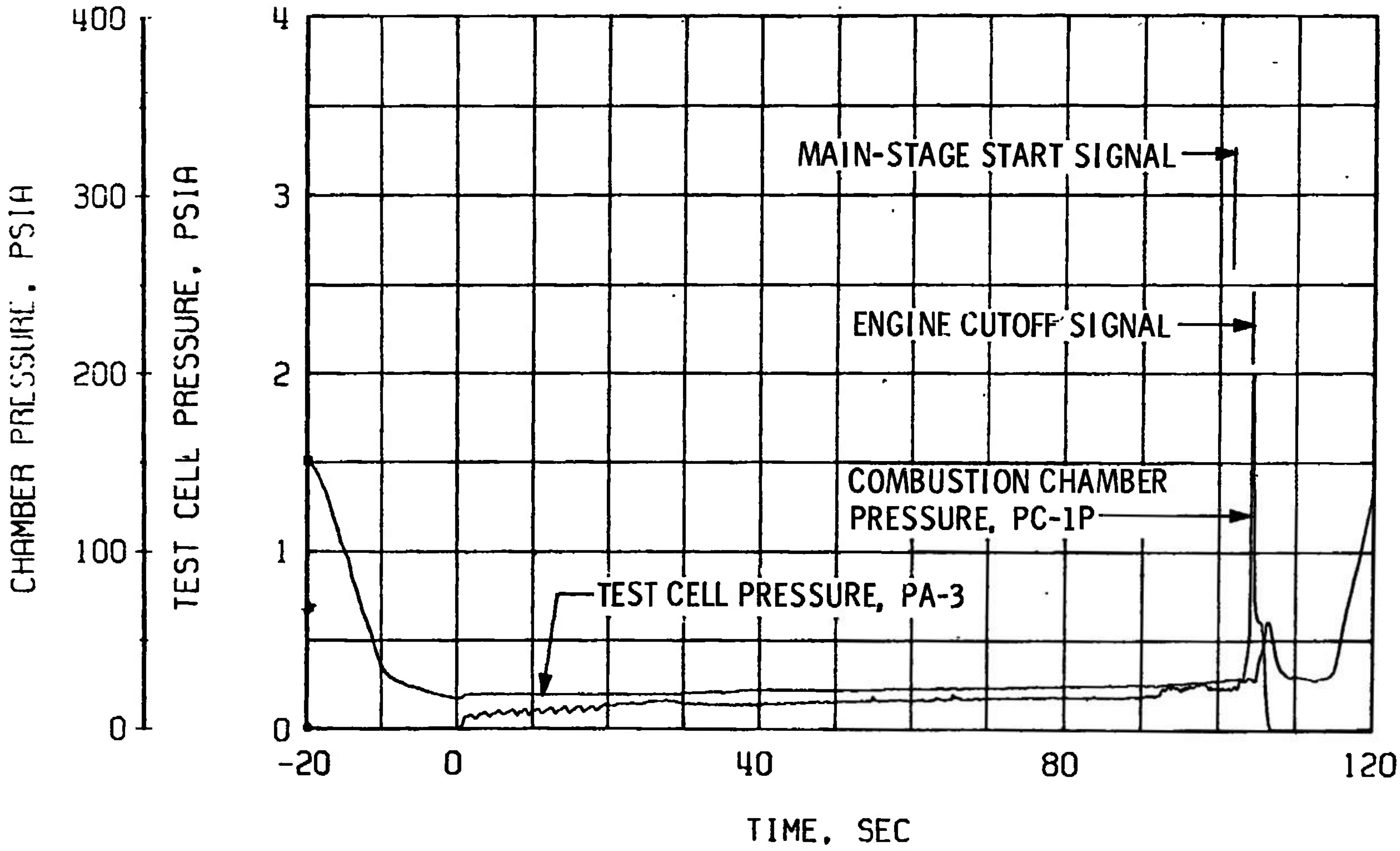
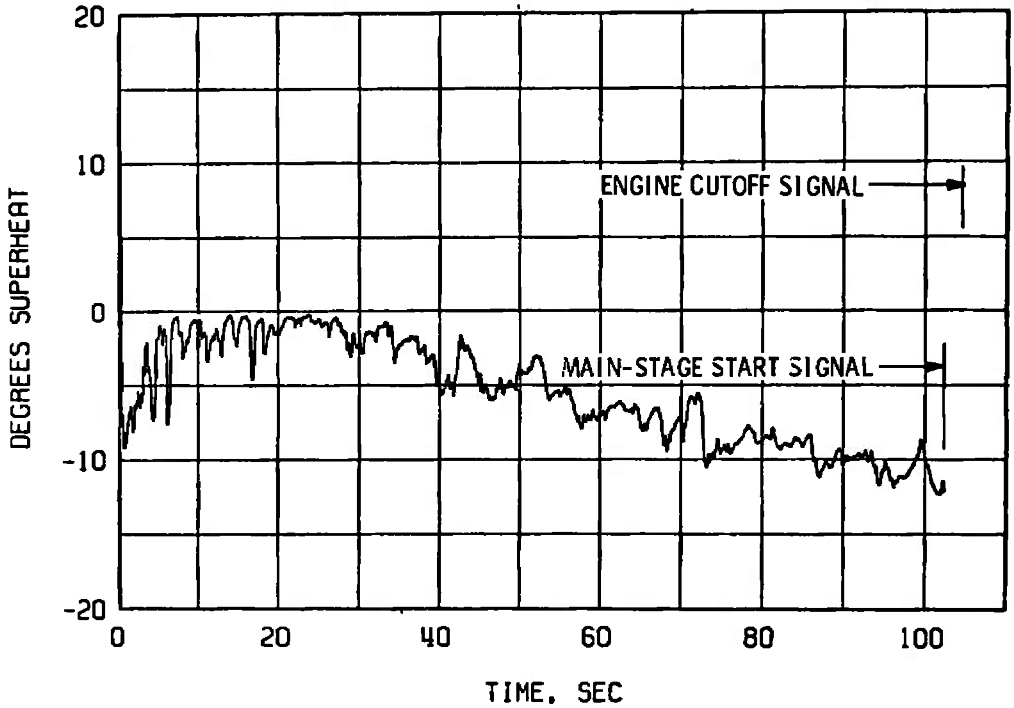
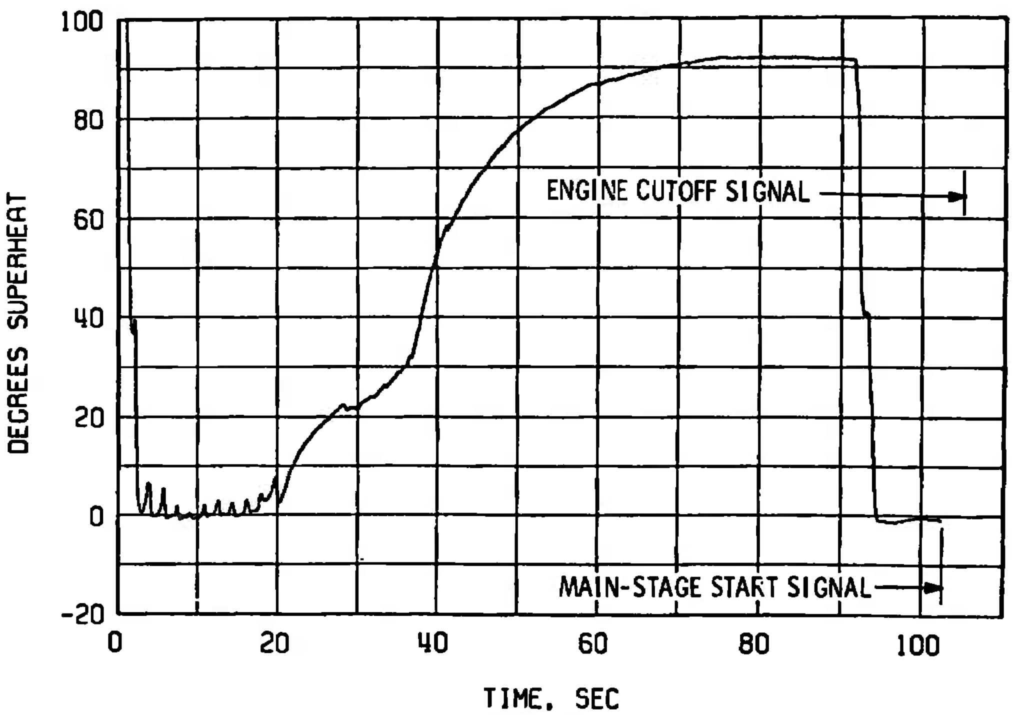



Fig. 51 Engine Ambient and Combustion Chamber Pressure, Firing 15C

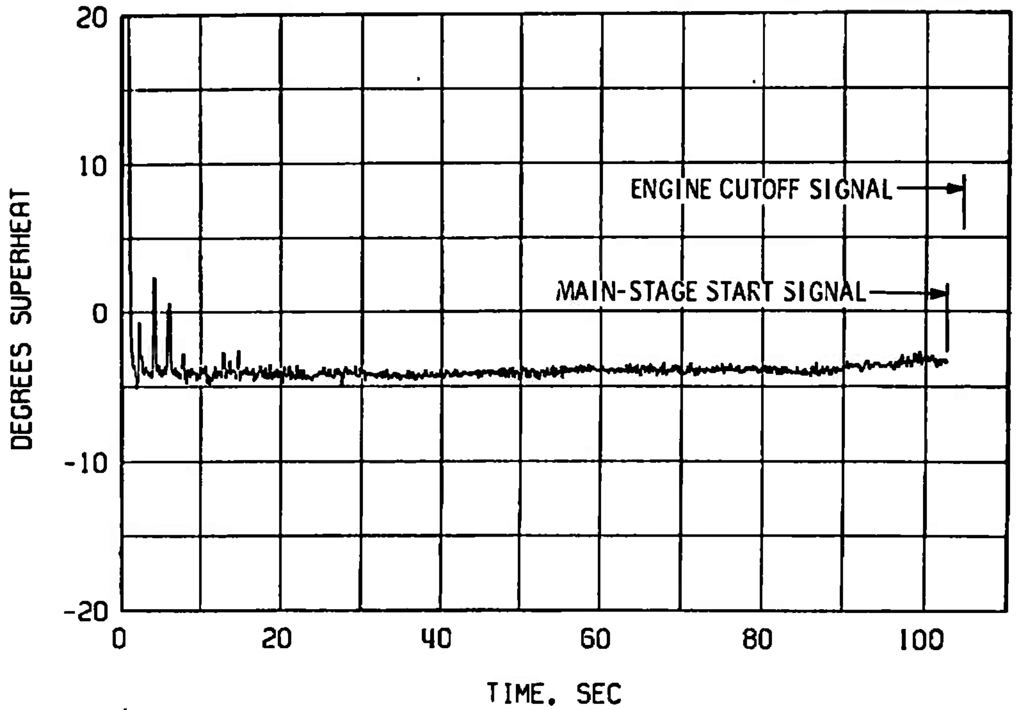



a. Oxidizer Pump Inlet

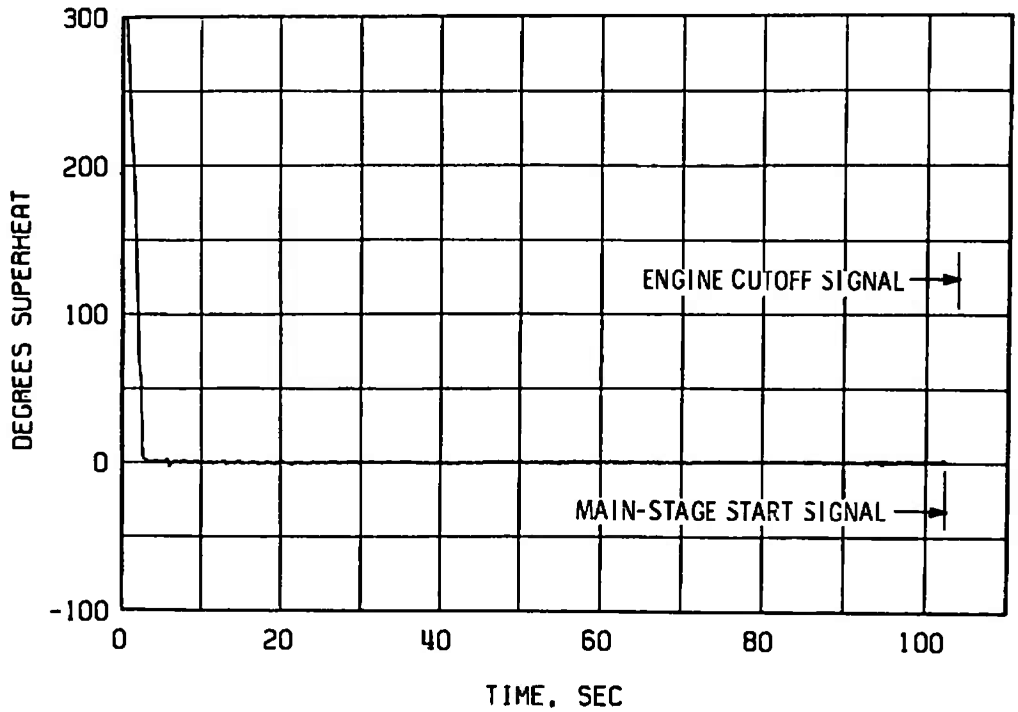



b. Oxidizer Pump Discharge

**Fig. 52 Propellant Feed System Condition during Idle Mode, Firing 15C**

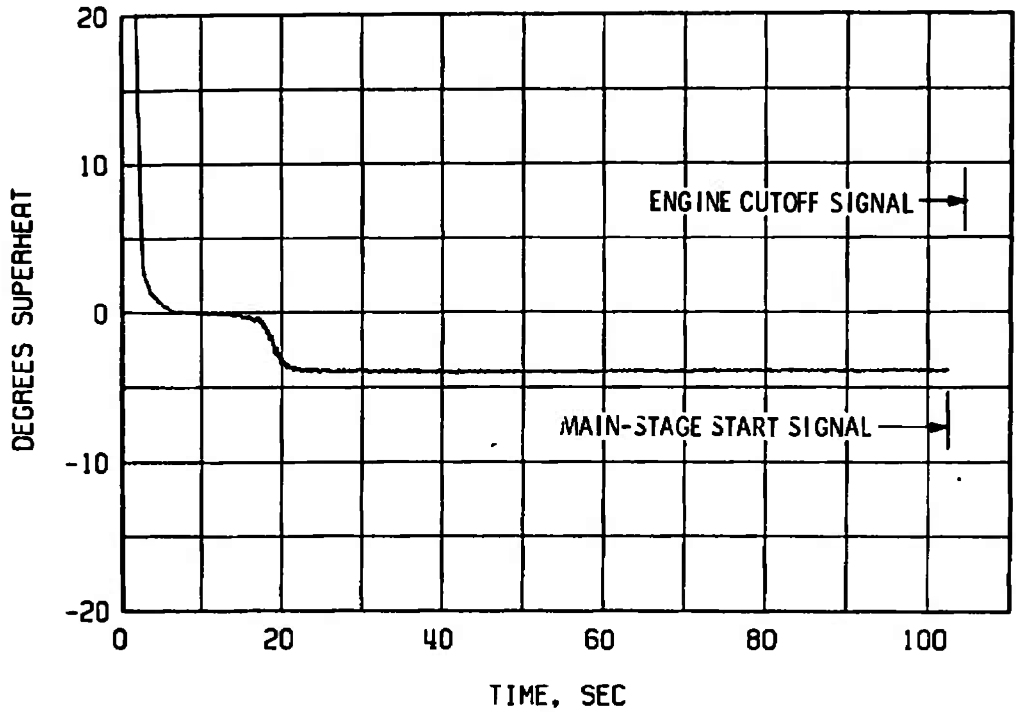



c. Oxidizer Idle-Mode Line

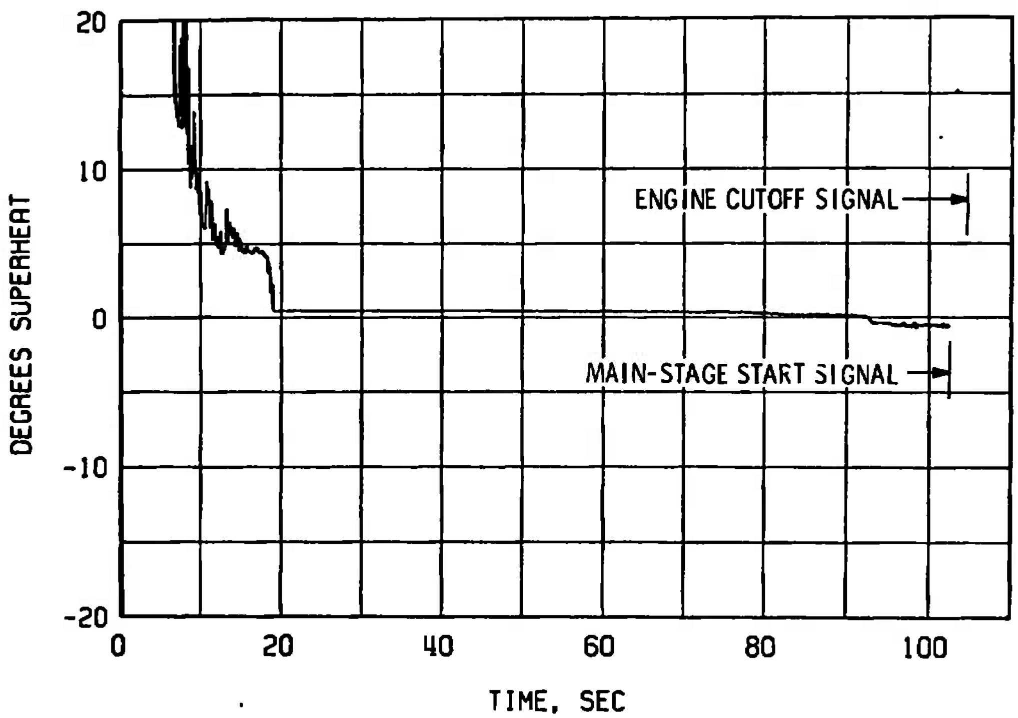



d. Oxidizer Injector

Fig. 52 Continued

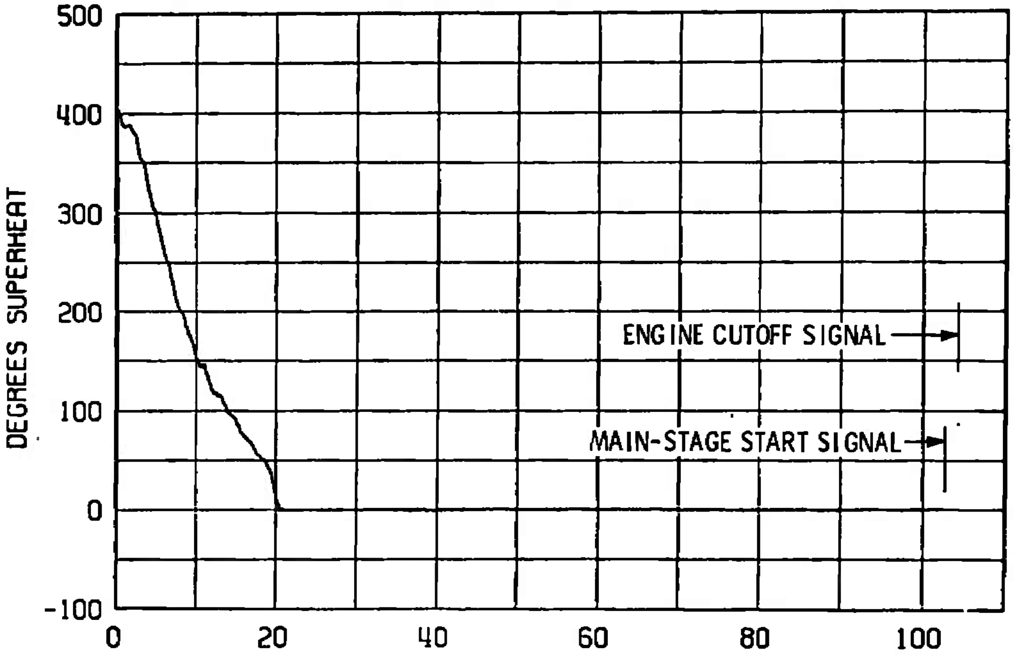



e. Fuel Pump Inlet




f. Fuel Pump Discharge

Fig. 52 Continued




g. Fuel Injector

Fig. 52 Concluded

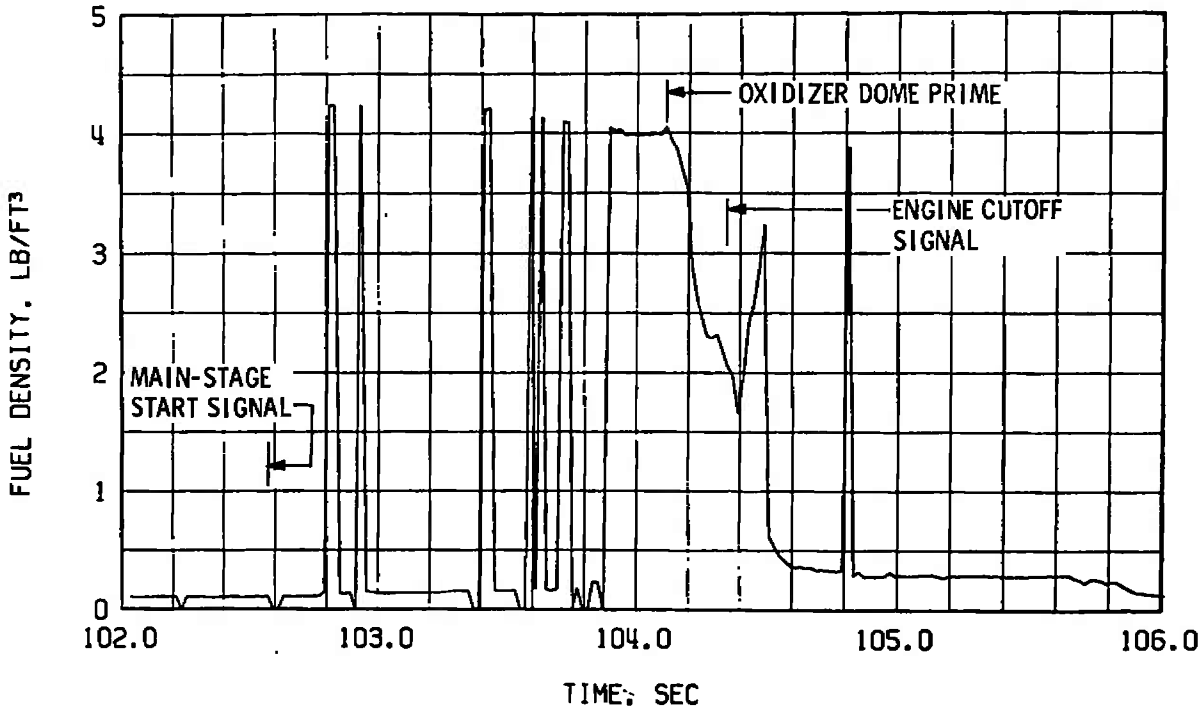



Fig. 53 Fuel Density at the Fuel Injector, Firing 15C

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1001-06)

| Part Name | P/N | S/N |
|---|---|---|
| Thrust Chamber Body Assembly | 99-210620 | 4094439 |
| Thrust Chamber Injector Assembly | XEOR 937173 | 4087380 |
| Augmented Spark Igniter Assembly | *EWR 113811-21 | 4901310 |
| Ignition Detector Probe No. 1 | 3243-2 | 016 |
| Ignition Detector Probe No. 2 | 3243-1 | 003X |
| Fuel Turbopump Assembly | 99-461500-31 | R004-1A |
| Oxidizer Turbopump Assembly | 99-460430-21 | S003-0A |
| Main Fuel Valve | 99-411320-X3 | 8900881 |
| Main Oxidizer Valve | 99-411225-X4 | 8900929 |
| Idle-Mode Valve | 99-411385 | 8900867 |
| Thrust Chamber Bypass Valve | 99-411180-X2 | 8900806 |
| Hot Gas Tapoff Valve | 99-557824-X2 | 8900847 |
| Propellant Utilization Valve | 99-251455-X5 | 8900911 |
| Electrical Control Package | 99-503670 | 4098176 |
| Engine Instrumentation Package | 99-704641 | 4097437 |
| Pneumatic Control Package | 99-558330 | 8900817 |
| Restart Control Assembly | 99-503680 | 4097867 |
| Helium Tank Assembly | NA5-260212-1 | 0002 |
| Oxidizer Flowmeter | 251216 | 4096874 |
| Fuel Flowmeter | 251225 | 4096875 |
| Fuel Inlet Duct Assembly | 409900-11 | 6631788 |
| Oxidizer Inlet Duct Assembly | 409899 | 4052289 |
| Fuel Pump Discharge Duct | 99-411082-7 | 439 |
| Oxidizer Pump Discharge Duct | 99-411082-5 | 439 |
| Thrust Chamber Bypass Duct | 99-411079 | 439 |
| Fuel Turbine Exhaust Bypass Duct | 307879-11 | 2143580 |
| Hot Gas Tapoff Duct | 99-411080-51 | 7239768 |
| Solid-Propellant Turbine Starters Manifold | 99-210921-11 | 7216433 |
| Heat Exchanger Assembly (Coil) | 307885 | 8363045 |
| Oxidizer Turbine Exhaust Duct | 307887 | 2142922 |
| Crossover Duct | 307879-11 | 2143580 |

*Rocketdyne Engineering Work Request

TABLE II
SUMMARY OF ENGINE ORIFICES

| Orifice Name | Part Number | Diameter, in. | Test Effective | Comments |
|---|---|---|---|---|
| Oxidizer Turbine Bypass | 99-210924 | 1.996<br>1.695 | J4-1902-05<br>J4-1001-07 | Delivered Part<br>EWR 121319 |
| Fuel Bypass | 99-406384 | 1.750<br>1.500 | J4-1001-06<br>J4-1001-08 | EWR 121311<br>EWR 121320 |
| Oxidizer Idle-Mode Supply Line | 99-411092 | 0.848<br>0.977<br>0.911 | J4-1001-06<br>J4-1001-07<br>J4-1001-15 | EWR 121308<br>EWR 121315<br>EWR 121386 |
| Main Oxidizer Valve Closing Control | 99-411279 | 33.25 scfm | J4-1902-05 | Thermostatic Orifice |
| Augmented Spark Igniter Oxidizer Supply Line | 652050 | 0.0999 | J4-1902-05 | Delivered Part |
| Augmented Spark Igniter Fuel Supply Line | | | J4-1902-05 | None Installed |
| Film Coolant | 99-411094 | 0.581 | J4-1902-08 | |
| Film Coolant Venturi | | 1.027 inlet<br>0.744 throat | J4-1902-05 | $C_D = 0.97$ |
| Propellant Utilization Valve Inlet | XEOR 934826 | 1.250 | J4-1902-05 | Delivered Part |

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1001-05 AND J4-1001-15)

| Modification Number | Completion Date | Description of Modification |
|---|---|---|
| | Test J4-1001-05, | 7/29/69 |
| 121306 | 8/22/69 | Load Cell Installation |
| 121307 | 8/24/69 | Decreased Main Oxidizer Valve 1st Stage Opening from 14 to 11.5 deg |
| | Test J4-1001-06, | 8/25/69 |
| 121314 | 8/27/69 | Decreased Main Oxidizer Valve 1st Stage Opening from 11.5 to 10.5 deg |
| 121317 | 8/27/69 | Insulated Oxidizer Idle-Mode Supply Line |
| 121319 | 8/27/69 | Decreased Hot Gas Tapoff Valve Mechanical Stop from 1.321 to 1.260 in. |
| 121357 | 8/27/69 | Insulated Oxidizer High Pressure Duct from Pump to Idle-Mode Valve |
| | Test J4-1001-07, | 8/28/69 |
| 121367 | 9/12/69 | Increased Hot Gas Tapoff Valve Mechanical Stop from 1.260 to 1.321 in. |
| 121369 | 9/12/69 | Repair Thrust Chamber Damage Found Post Test J4-1001-09 |
| | Test J4-1001-11, | 9/17/69 |
| 121326 | 9/30/69 | Installed Oxidizer Pump Seal Drain Shutoff Valve |
| 121382 | 10/9/69 | Repair Thrust Chamber Damage Found Post Test J4-1001-13 |
| 121329 | 10/14/69 | Removed Bypass Line in the Fuel Augmented Spark Igniter Supply Line (Back to Original Configuration) |
| 121384 | 10/28/69 | Increased Main Oxidizer Valve 1st Stage Opening from 10.5 to 11.7 deg |
| | Test J4-1001-15, | 10/29/69 |

# TABLE IV
## ENGINE COMPONENT REPLACEMENTS
## (BETWEEN TESTS J4-1001-05 AND J4-1001-15)

| Replacement | Completion Date | Component Replaced |
|---|---|---|
| | Test J4-1001-05, 7/29/69 | |
| P/N 558022<br>S/N 2137946 | 8/22/69 | Helium Fill Check Valve P/N 558022, S/N 2137943 |
| P/N XEOR 937173<br>S/N 4087380 | 8/22/69 | Thrust Chamber Injector Assembly, P/N XEOR 936648, S/N 4087384 |
| P/N C-47930<br>S/N 645700 | 8/22/69 | Gimbal Bearing Assembly P/N 208900, S/N 8362333 |
| | Test J4-1001-06, 8/25/69 | |
| | None | |
| | Test J4-1001-07, 8/28/69 | |
| | None | |
| | Test J4-1001-11, 9/17/69 | |
| P/N 309065-31<br>S/N 2203033<br>(Poppet) | 10/8/69 | Hot Gas Check Valve (Flapper), P/N 309065, S/N 2138829 |
| P/N 210610-81<br>S/N 4087387 | 10/10/69 | Thrust Chamber Injector Assembly, P/N XEOR 937173, S/N 4087380 |
| P/N 99-503670-21<br>S/N 4097588 | 10/28/69 | Electrical Control Assembly, P/N 99-503670 S/N 4098176 |
| | Test J4-1001-15, 10/29/69 | |

## TABLE V
## ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

| Purge | Requirement | SPTS Installed | Air On | Propellant Drop | Engine Start | Cutoff / Coast Period | Propellant Drop | Restart | Cutoff (Last Firing) | Air Off |
|---|---|---|---|---|---|---|---|---|---|---|
| Oxidizer dome and idle-mode diffuser | Nitrogen, 600 ± 25 psia 100 to 150°F at customer connect panel (150 scfm) | | | | | | | | | |
| Thrust chamber jacket, film coolant, and turbopump purges | Helium, 150 + 25 psia 50 to 150°F at customer con-nect panel (125 scfm) | | ** † | | (*) | 15 min (**) (†) | | (*) | 30 min | |
| SPTS conditioning | Nitrogen, -50 to 140°F | 1, 2, and 3 | | | | Remaining SPTS | | | | |
| Main fuel valve conditioning | Helium, -300°F to ambient | | | †† | | | | | | |

*Engine-supplied oxidizer pump intermediate seal cavity purge
**Anytime facility water is on
†30 min before propellant drop
††Initiate mfv conditioning 30 min before engine start for those firings with temperature requirements

## TABLE VI
## SUMMARY OF TEST REQUIREMENTS AND RESULTS

| FIRING NUMBER | | J4-1001-06A Target | J4-1001-06A Actual | J4-1001-06B Target | J4-1001-06B Actual | J4-1001-07A Target | J4-1001-07A Actual | J4-1001-07B Target | J4-1001-07B Actual | J4-1001-07C Target | J4-1001-07C Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRING DATE/TIME OF DAY | | 8/25/69 | 1209 | 9/25/68 | 1339 | 8/28/69 | 1235 | 8/28/68 | 1405 | 8/28/69 | 1715 |
| Pressure Altitude at t-0, ft (Ref. 1) | | 100,000 | 102,000 | 100,000 | 96,000 | 100,000 | 95,000 | 100,000 | 99,000 | 100,000 | 100,000 |
| Low Thrust Idle-Mode Duration, sec * | | 1.0 | 1.01 | 50.0 | 50.06 | 50.0 | 49.62 | 50.0 | 50.90 | 50.0 | 50.01 |
| Main-Stage Duration, sec * | | 7.5 | 7.68 | 7.5 | 1.52 | 7.5 | 7.78 | 7.5 | 7.42 | 7.5 | 7.62 |
| Post-Main-Stage Idle-Mode Duration, sec * | | 10.0 | 10.25 | 10.0 | – | 10.0 | 10.28 | 10.0 | 10.49 | – | – |
| Fuel Pump Inlet Pressure at t-0, psia | | 33±1.0 | 33.0 | 33±1.0 | 33.3 | 33±1.0 | 33.2 | 33±1.0 | 33.4 | 40±1.0 | 41.8 |
| Fuel Pump Inlet Temperature at t-0, °F | | – | -416.8 | – | -413.2 | – | -417.8 | – | -203.6 | – | -416.1 |
| Fuel Tank Bulk Temperature at t-0, °F | | -422.0±0.4 | -422.4 | -422.0±0.4 | -422.3 | -422.0±0.4 | -422.4 | -422.0±0.4 | -422.1 | -422.0±0.4 | -422.0 |
| Oxidizer Pump Inlet Pressure at t-0, psia | | 39±1.0 | 39.8 | 39±1.0 | 39.3 | 39±1.0 | 39.2 | 46±1.0 | 46.0 | 39±1.0 | 39.3 |
| Oxidizer Pump Inlet Temperature at t-0, °F | | – | -292.2 | – | -279.6 | – | -291.2 | – | -278.4 | – | -278.6 |
| Oxidizer Tank Bulk Temperature at t-0, °F | | -295.0±0.4 | -295.4 | -295.0±0.4 | -295.4 | -295.0±0.4 | -294.6 | -295.0±0.4 | -295.0 | -285.0±0.4 | -295.1 |
| Helium Tank Pressure at t-0, psia | | $3450^{+0}_{-200}$ | 3430 | Remains From "A" | 3200 | $3450^{+0}_{-200}$ | 3410 | Remains From "A" | 3196 | Remains From "B" | 3007 |
| Helium Tank Temperature at t-0, °F | | – | 101 | – | 81 | – | 111 | – | 83 | – | 78 |
| Main Fuel Valve Temperature at t-0, °F | | $-100^{+0}_{-50}$ | -128 | – | – | – | 92 | – | 112 | – | 103 |
| Augmented Spark Igniter Ignition Detected, sec (Ref. t-0)* | | 0.686 | | 0.511 | | 0.534 | | 0.349 | | 0.588 | |
| Propellant Utilization Valve Position at t-0 | | NULL | | NULL | | NULL | | NULL | | NULL | |
| Thrust Chamber Temperature at t-0, °F | | $-100^{+0}_{-50}$ | 63 | – | 31 | – | 74 | – | 67 | – | 70 |
| Oxidizer Pump Bearing Temperature at t-5, °F | | – | -288 | -100±20 | -116 | – | -288 | -100±30 | -84 | -100±30 | -278 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| Solid-Prupellant Turbine Starter | Part Number | 99803527-11 | | 99803527-11 | | 99803527-11 | | 99803527-11 | | 98803527-11 | |
| | Serial Number | RT000013 | | RT000014 | | RT000019 | | RT000020 | | RT000021 | |
| | Temperature at t-0, °F | 50±10 | 40 | 50±10 | 41 | 50±10 | 44 | 130±10 | 120 | 50±10 | 49 |
| | Burn Time, sec * | 2.234 | | 2.242 | | 2.400 | | 1.975 | | 2.320 | |
| | Maximum Pressure, psia | 3510 | | 3565 | | 3275 | | 3824 | | 3255 | |
| | | | | | | | | | | | |

| FIRING NUMBER | | J4-1001-11A Target | J4-1001-11A Actual | J4-1001-11B Target | J4-1001-11B Actual | J4-1001-11C Target | J4-1001-11C Actual | J4-1001-15A Target | J4-1001-15A Actual | J4-1001-15B Target | J4-1001-15B Actual | J4-1001-15C Target | J4-1001-15C Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRING DATE/TIME OF DAY | | 9/17/69 | 1254 | 9/17/69 | 1509 | 9/17/69 | 2036 | 10/29/69 | 1521 | 10/29/69 | 1919 | 10/29/69 | 2025 |
| Pressure Altitude at t-0, ft (Ref. 1) | | 100,000 | 80,000 | 100,000 | 100,000 | 100,000 | 107,000 | 100,000 | 108,000 | 100,000 | 109,100 | 100,000 | 98,000 |
| Low Thrust Idle-Mode Duration, sec * | | 100.0 | 98.12 | 75.0 | 75.98 | 100.0 | 88.73 | 1.0 | 1.02 | 100.0 | 102.71 | 100.0 | 102.54 |
| Main-Stage Duration, sec * | | 5.0 | 1.33 | 4.5 | 4.74 | 4.5 | 1.68 | 2.4 | 2.43 | 2.4 | 2.42 | 2.4 | 1.79 |
| Post-Main-Stage Idle-Mode Duration, sec * | | 10.0 | – | – | – | – | – | – | – | – | – | – | – |
| Fuel Pump Inlet Pressure at t-0, psia | | 40.0±1.0 | 41.1 | 27.0±1.0 | 27.9 | 40.0±1.0 | 39.7 | 30±1 | 29.9 | 28±1 | 30.1 | 33±1 | 32.4 |
| Fuel Pump Inlet Temperature at t-0, °F | | – | – | – | -419.0 | – | -295.6 | – | -418.5 | – | -417.8 | – | -210.5 |
| Fuel Tank Bulk Temperature at t-0, °F | | -422.0±0.4 | -422.5 | -422.0±0.4 | -422.4 | -422.0±0.4 | -422.4 | -422.0±0.4 | -422.8 | -422.0±0.4 | -422.2 | -422.0±0.4 | -422.4 |
| Oxidizer Pump Inlet Pressure at t-0, psia | | 33.0±1.0 | 39.7 | 33.0±1.0 | 40.3 | 33.0±1.0 | 31.7 | 39±1 | 39.2 | 44±1 | 44.7 | 34±1 | 32.5 |
| Oxidizer Pump Inlet Temperature at t-0, °F | | – | -117.4 | – | -277.1 | – | -291.0 | – | -292.6 | – | -278.9 | – | -290.1 |
| Oxidizer Tank Bulk Temperature at t-0, °F | | -295.0±0.4 | -295.2 | -295.0±0.4 | -295.3 | -295.0±0.4 | -294.9 | -295.0±0.4 | -295.5 | -295.0±0.4 | -295.7 | -295.0±0.4 | -294.7 |
| Helium Tank Pressure at t-0, psia | | $3450^{+0}_{-200}$ | 3318 | Remains From "A" | 2982 | Remains From "B" | 2900 | $3450^{10}_{-200}$ | 3383 | Remains From "A" | 3092 | Remains From "B" | 2883 |
| Helium Tank Temperature at t-0, °F | | – | 119 | – | 77 | – | 85 | – | 112 | – | 82 | – | 68 |
| Main Fuel Valve Temperature at t-0, °F | | – | 106 | – | 90 | – | 108 | $-100^{+0}_{-50}$ | -121 | – | -305 | – | -39 |
| Augmented Spark Igniter Ignition Detected, sec (Ref. t-0)* | | 0.698 | | 0.518 | | 0.849 | | 0.485 | | 0.380 | | 0.640 | |
| Propellant Utilization Valve Position at t-0 | | NULL | | NULL | | NULL | | NULL | | NULL | | NULL | |
| Thrust Chamber Temperature at t-0, °F | | – | 70 | – | 1 | – | 67 | – | 59 | -200±50 | -187 | -25±25 | 3 |
| Oxidizer Pump Bearing Temperature at t-5, °F | | – | 98 | – | -276 | -100±20 | -128 | – | -288 | – | -292 | -25±25 | -64 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Solid-Prupellant Turbine Starter | Part Number | 99803527-11 | | 99803527-11 | | 99803527-11 | | 99803527-11 | | 99803527-11 | | 99803527-11 | |
| | Serial Number | RT000015 | | RT000022 | | RT000027 | | RT000028 | | RT000029 | | RT000006 | |
| | Temperature at t-0, °F | 130±10 | 132 | 130±10 | 123 | 50±10 | 38 | 50±10 | 78 | 50±10 | 57 | 50±10 | 52 |
| | Burn Time, sec * | 1.929 | | 1.965 | | 2.386 | | 2.190 | | 1.903 | | 2.330 | |
| | Maximum Pressure, psia | 4108 | | 3856 | | 3317 | | 3498 | | 3504 | | 3361 | |
| | | | | | | | | | | | | | |

*Data ruduced from oscillogram

# TABLE VII
# ENGINE VALVE TIMINGS

| KA1061 | Firing | Start | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Main Fuel Valve | | | Idle-Mode Oxidizer Valve | | | Hot Gas Tapoff Valve | | | Main Oxidizer Valve First Stage | | | Main Oxidizer Valve Second Stage | | | Thrust Chamber Bypass Valve | | |
| | | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec |
| 00 | Final Sequence | 0.0 | 0.045 | 0.064 | 0.0 | 0.115 | 0.045 | 4.003 | 0.158 | 0.080 | 4.502 | 0.064 | 0.032 | 5.551 | 0.162 | 0.530 | 8.891 | 0.220 | 0.855 |
| 06 | A | 0.0 | 0.052 | 0.040 | 0.0 | 0.130 | 0.040 | 1.012 | 0.180 | 0.080 | 1.012 | 0.007 | 0.033 | 2.800 | 0.242 | 0.850 | 8.090 | 0.155 | 1.055 |
| 06 | B | 0.0 | 0.052 | 0.052 | 0.0 | 0.117 | 0.057 | 50.023 | 0.157 | 0.083 | 50.062 | 1.050 | 0.028 | N/A | --- | --- | N/A | --- | -- |
| 07 | Final Sequence | 0.0 | 0.048 | 0.040 | 0.0 | 0.118 | 0.042 | 5.430 | 0.153 | 0.091 | 8.480 | 0.054 | 0.020 | 8.315 | 0.158 | 0.525 | 5.315 | 0.318 | 0.875 |
| 07 | A | 0.0 | 0.050 | 0.044 | 0.0 | 0.112 | 0.040 | 50.872 | 0.155 | [illegible] | 50.078 | 0.070 | 0.027 | 51.517 | 0.150 | 0.890 | 01.517 | 0.150 | 1.105 |
| 07 | B | 2.0 | 0.050 | 0.045 | 0.0 | 0.110 | 0.041 | 50.960 | 0.160 | 2.085 | 53.020 | 0.082 | 0.028 | 83.702 | 0.301 | 2.835 | 53.798 | 0.180 | 1.810 |
| 07 | C | 0.0 | 0.050 | 0.058 | 0.0 | 0.115 | 0.240 | 50.2.0 | 0.153 | 0.090 | 50.010 | 0.278 | 3.022 | 51.833 | 0.153 | 0.028 | 5.833 | 0.190 | .850 |
| 11 | Final Sequence | 0.3 | 0.043 | 0.361 | 0.0 | 0.118 | 0.042 | 4.078 | 0.141 | 0.085 | 4.252 | 0.082 | 0.050 | 5.052 | 0.105 | 0.020 | 5.052 | 0.170 | 0.886 |
| 11 | A | 0.3 | 0.053 | 0.348 | 0.0 | 0.113 | 0.042 | 58.134 | 0.152 | 0.350 | 56.134 | 0.063 | 0.324 | N/A | --- | --- | N/A | --- | --- |
| 11 | B | 0.0 | 0.053 | 0.049 | 0.0 | 2.115 | 0.043 | 75.874 | 0.105 | 0.578 | 70.874 | 0.083 | 0.320 | 77.570 | 0.225 | 0.564 | 77.570 | 0.198 | 1.152 |
| 11 | C | 0.0 | 0.054 | 8.051 | 2.0 | 0.115 | 0.040 | 80.782 | 0.128 | 0.088 | 80.720 | 0.080 | 0.028 | N/A | --- | --- | N/A | --- | --- |
| 25 | Final Sequence | 0.0 | 0.020 | 0.065 | 0.0 | 0.117 | 0.040 | 11.685 | 0.152 | 0.063 | 11.685 | 0.080 | 0.030 | N/A | --- | --- | N/A | --- | --- |
| 18 | A | 0.0 | 0.053 | 0.058 | 0.0 | 0.128 | 0.048 | 1.020 | 0.157 | 0.085 | 1.020 | 0.053 | 0.020 | N/A | --- | --- | N/A | --- | --- |
| 15 | B | 0.0 | 0.067 | 5.055 | 0.0 | 0.155 | 0.040 | 102.71 | 0.123 | 0.050 | 102.71 | 0.050 | 0.030 | N/A | --- | --- | N/A | --- | --- |
| 15 | C | 0.0 | 0.020 | 0.060 | 0.0 | 0.121 | 0.042 | 102.54 | 0.158 | 0.053 | 108.04 | 0.050 | 0.029 | N/A | --- | --- | N/A | --- | --- |

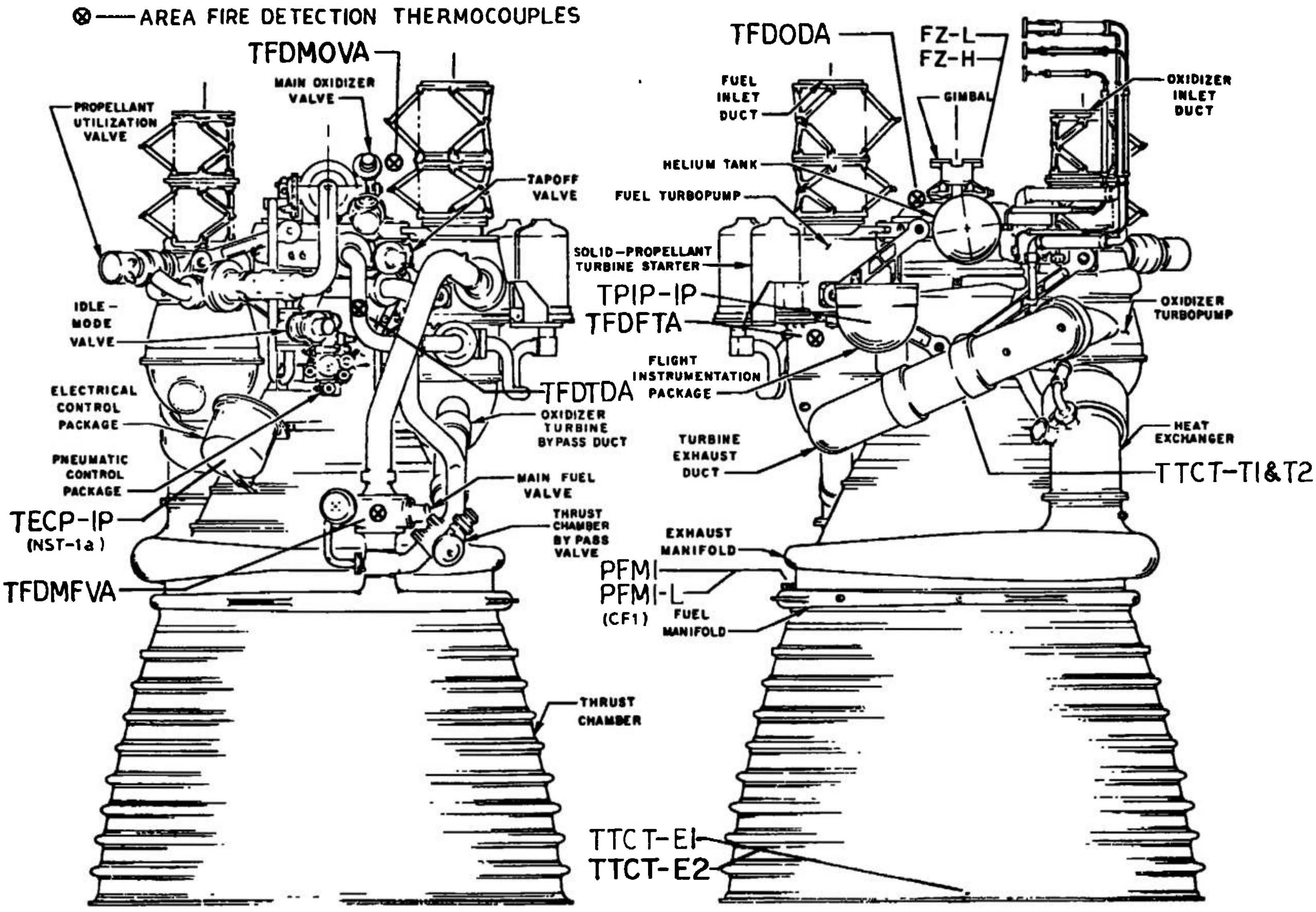
| KA1001 | Firing | Shutdown | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Main Oxidizer Valve | | | Hot Gas Tapoff Valve | | | Main Fuel Valve | | | Idle-Mode Oxidizer Valve | | | Thrust Chamber Bypass Valve | | |
| | | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec |
| 06 | Final Sequence | 12.364 | 0.301 | 2.145 | 18.364 | 0.067 | 0.845 | 17.278 | 0.073 | 0.251 | 37.278 | 0.069 | 0.153 | 12.354 | 0.280 | 0.228 |
| 05 | A | 8.528 | 0.084 | 0.155 | 8.585 | 0.084 | 0.230 | 15.515 | 3.075 | 0.325 | 18.815 | 0.072 | 0.150 | 8.808 | 0.342 | 0.810 |
| 05 | B | 51.586 | 0.040[5] | 0.030[5] | 51.288 | 0.044 | 0.224 | 51.588 | 0.074 | 0.250 | 51.505 | 0.084 | 0.122 | N/A | --- | --- |
| 07 | Final Sequence | 13.574 | 0.088 | 0.145 | 19.874 | 0.055 | 0.255 | 13.874 | 0.083 | 0.367 | 13.874 | 0.078 | 0.113 | 13.574 | 0.285 | 0.220 |
| 07 | A | 57.402 | 0.085 | 0.150 | 57.403 | 0.055 | 0.252 | 87.498 | 0.060 | 0.251 | 07.485 | 0.055 | 0.150 | 87.402 | 0.340 | 0.171 |
| 07 | B | 55.317 | 0.073 | 0.186 | 58.817 | 0.052 | 0.250 | 08.505 | 0.070 | 0.250 | 85.805 | 0.080 | 0.175 | 58.317 | 0.231 | 0.175 |
| 07 | C | 57.533 | 0.075 | 0.153 | 57.032 | 0.050 | 0.240 | 37.535 | 0.075 | 0.270 | 57.835 | 0.075 | 0.181 | 57.635 | 0.315 | 0.155 |
| 11 | Final Sequence | 0.135 | 0.082 | 0.144 | 2.135 | 0.370 | 0.830 | 5.136 | 0.360 | 0.253 | 2.125 | 0.275 | 0.312 | 9.135 | 0.287 | 0.222 |
| 11 | A | 82.442 | 0.040[5] | 0.030[5] | 92.845 | 0.260 | 0.820 | 29.448 | 0.073 | 3.242 | 25.442 | 0.083 | 0.102 | N/A | --- | --- |
| 11 | B | 85.722 | 0.080 | 0.173 | 30.783 | 0.070 | 0.220 | 80.723 | 0.062 | 0.830 | 50.723 | 0.080 | 0.152 | 30.788 | 0.323 | 0.150 |
| 11 | C | 100.322 | 0.040[5] | 0.018[2] | 100.362 | 0.072 | 0.210 | 106.362 | 0.072 | 0.252 | 100.268 | 0.077 | 0.124 | N/A | --- | --- |
| 18 | Final Sequence | 14.118 | 0.040[5] | 0.028[5] | 14.118 | 0.063 | 0.220 | 14.112 | 0.074 | 0.258 | 14.112 | 0.082 | 0.140 | N/A | --- | --- |
| 18 | A | 2.447 | 0.041[5] | 0.035[0] | 3.447 | 0.065 | 0.251 | 3.447 | 0.055 | 0.328 | 3.447 | 0.075 | 0.145 | N/A | --- | --- |
| 18 | B | 102.12 | 0.033[5] | 0.020[5] | 105.13 | 0.070 | 0.222 | 105.12 | 0.095 | 0.455 | 105.13 | 0.080 | 0.145 | N/A | --- | --- |
| 18 | C | 104.23 | 0.040[5] | 0.030[5] | 104.33 | 0.070 | 0.205 | 104.83 | 0.050 | 0.200 | 104.33 | 0.070 | 0.102 | N/A | --- | --- |

Notes: 1. All valve signal times are referenced to 1-0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized
3. Final sequence check is conducted without propellants and within 12 hours before testing
4 Data are reduced from oscillograph
5 Main oxidizer valve first stage only

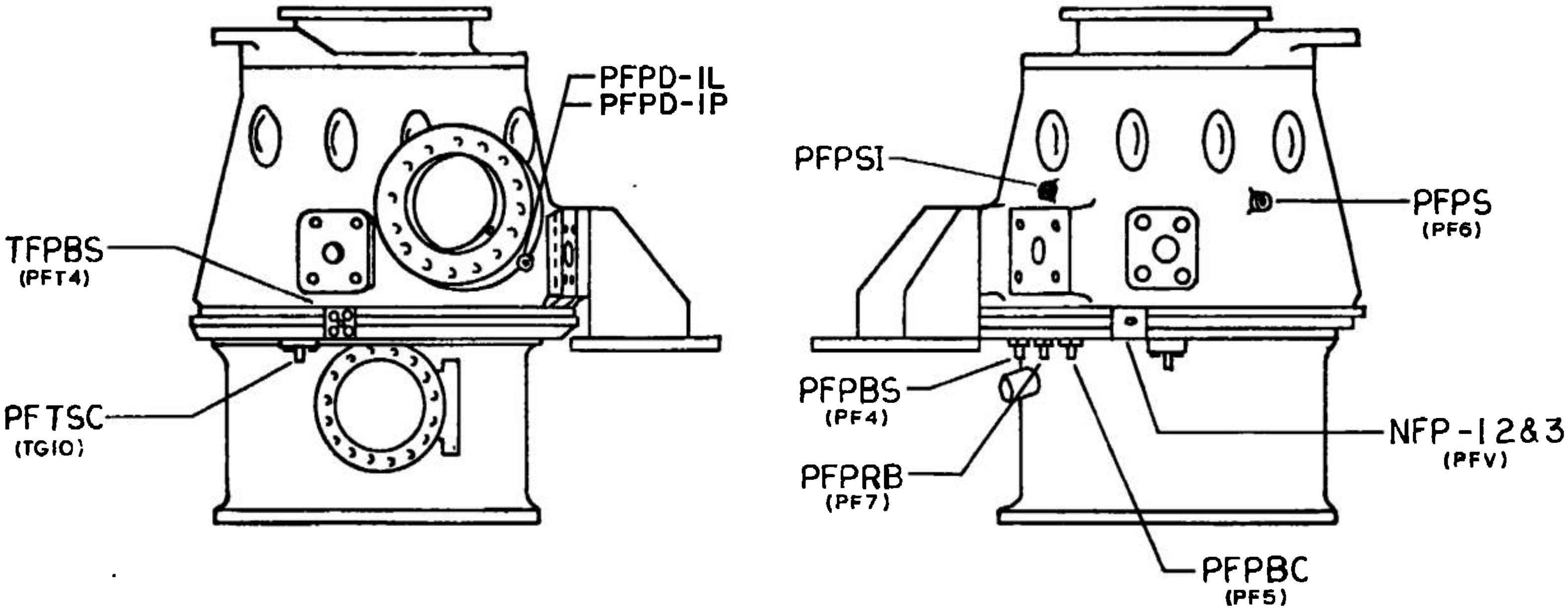
## APPENDIX III

## INSTRUMENTATION

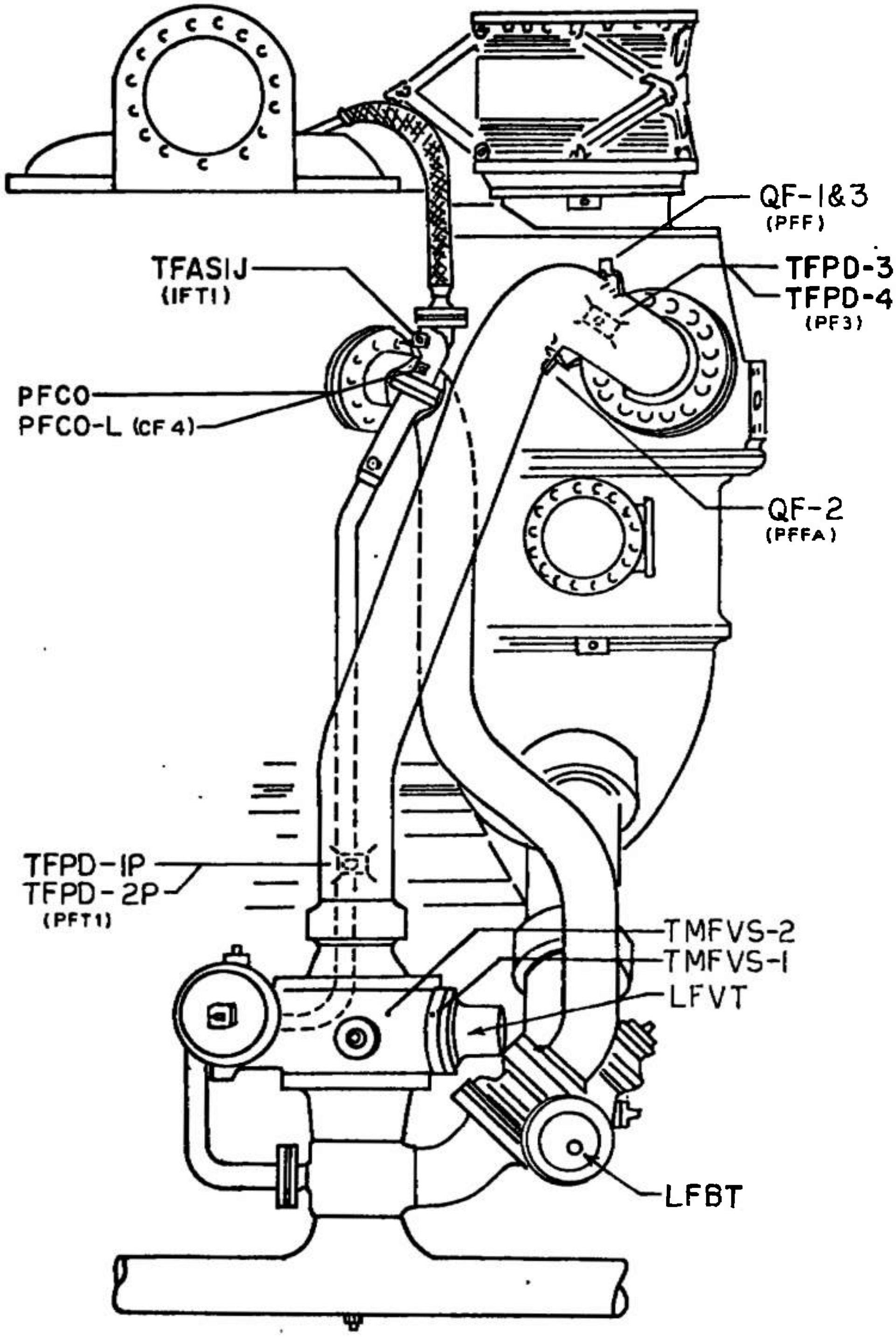
The instrumentation for AEDC tests J4-1001-06, -07, -11, and J4-1001-15 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.



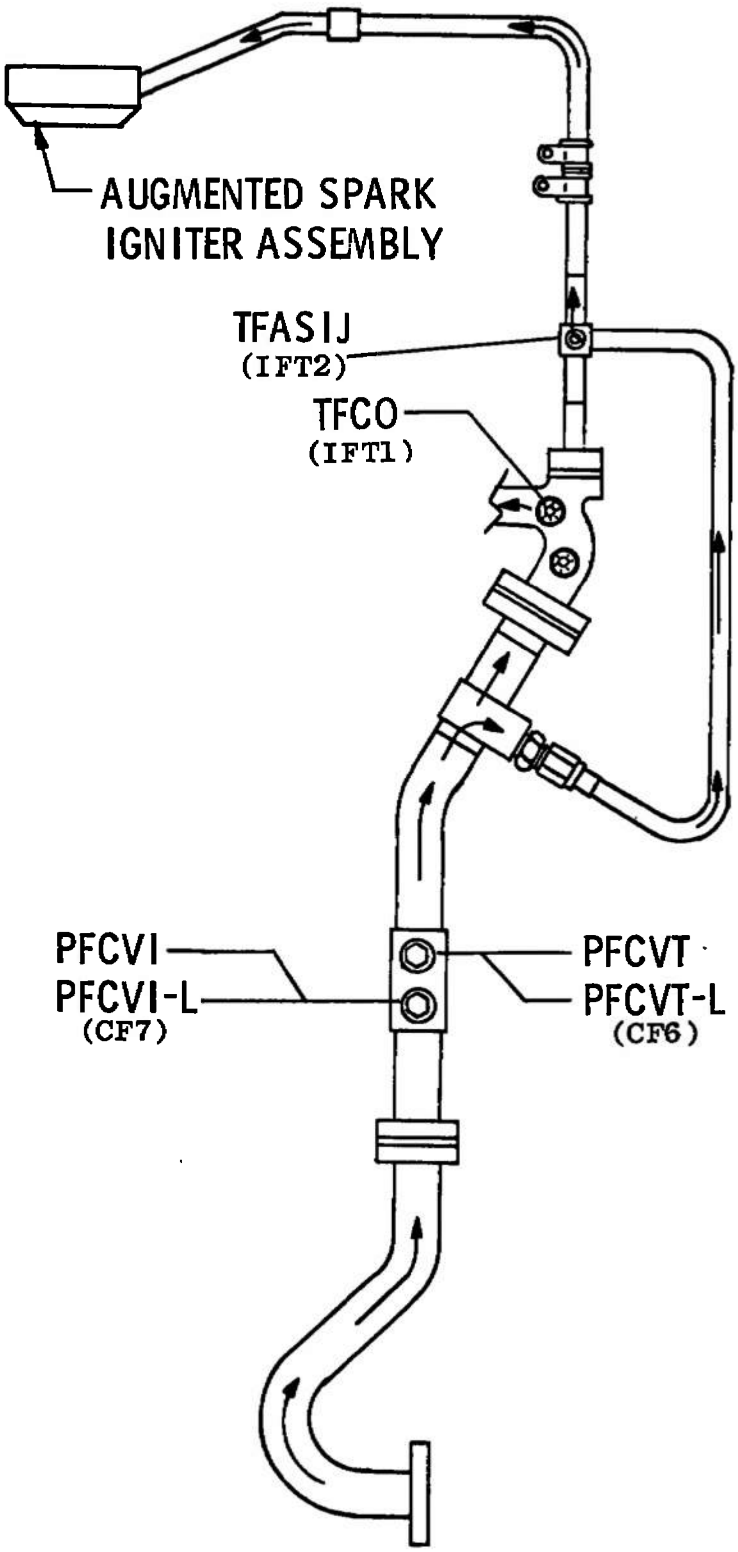

a. General Arrangement
Fig. III-1 Selected Sensor Locations



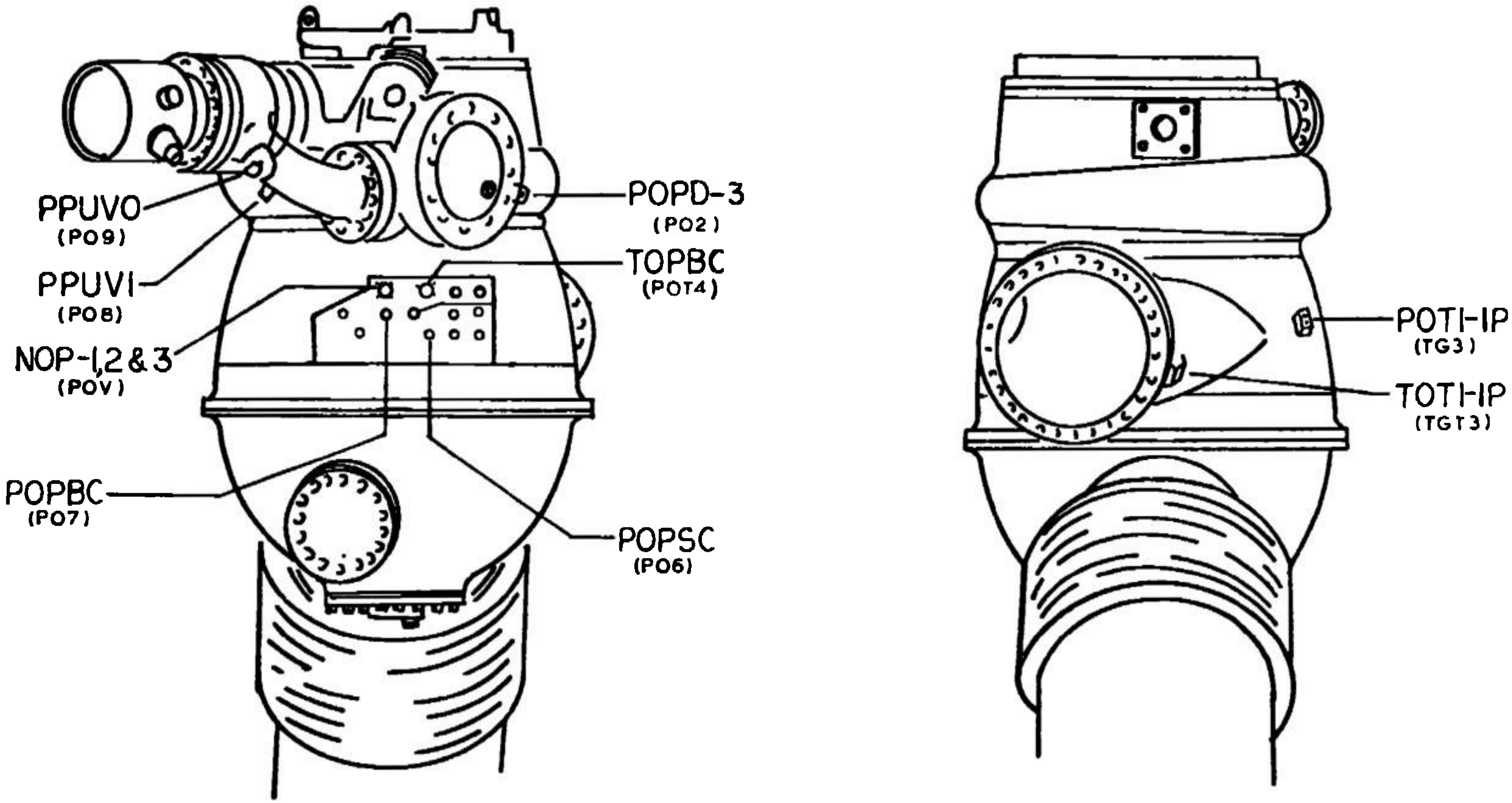

b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



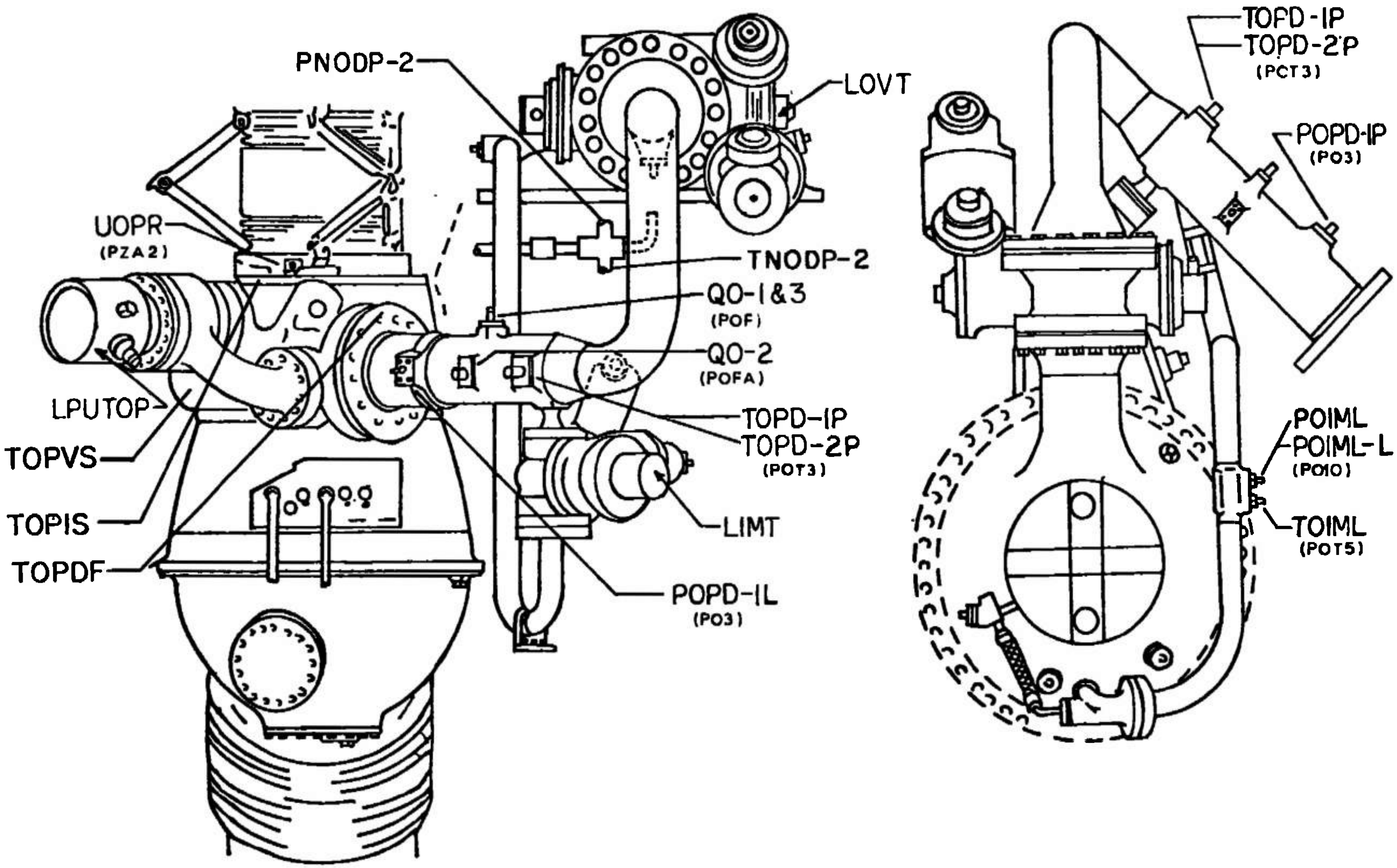

c. Fuel System Sensor Locations
Fig. III-1 Continued



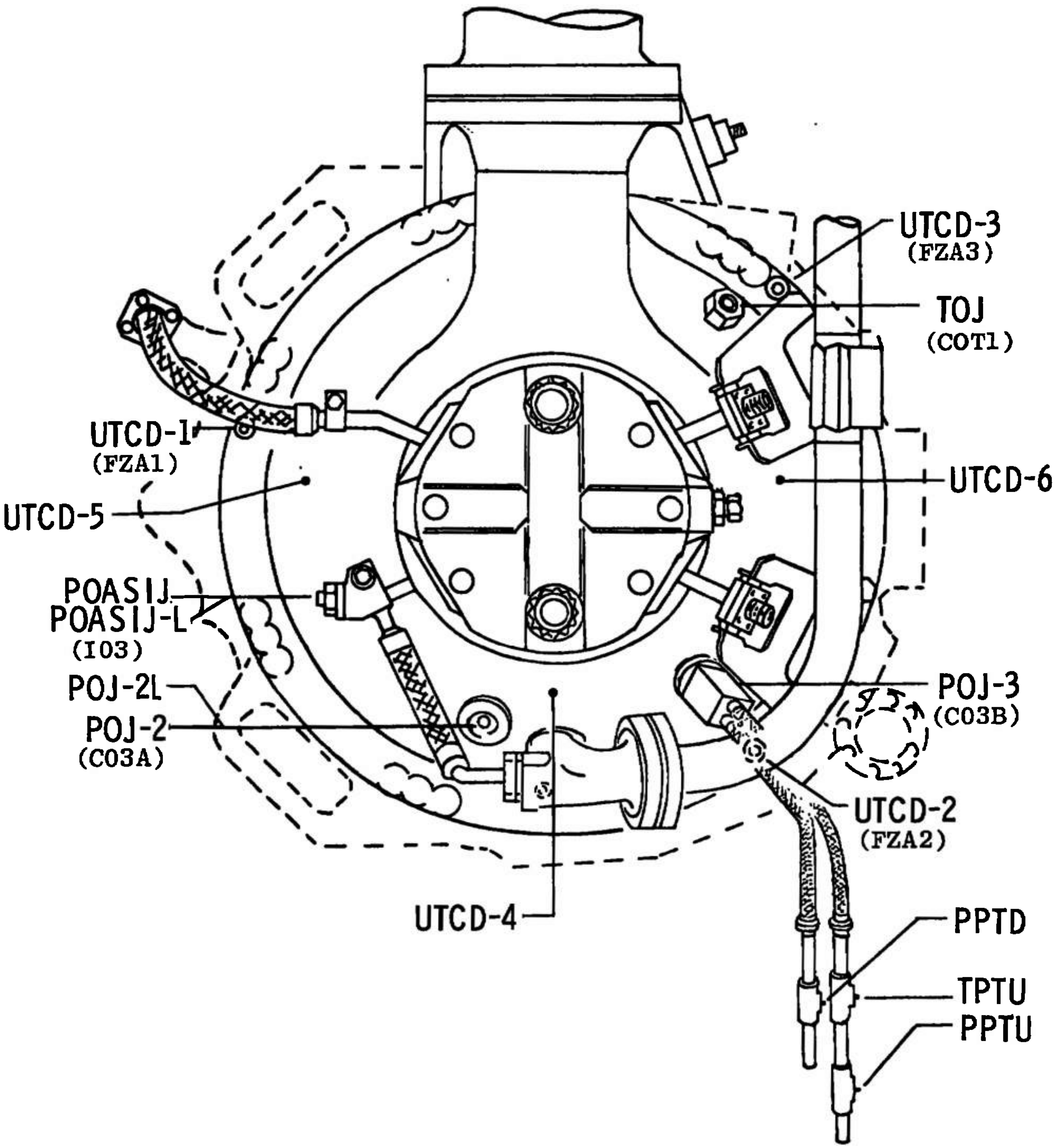

d. Fuel Film Coolant and Augmented Spark Igniter Supply Line Sensor Locations
Fig. III-1 Continued



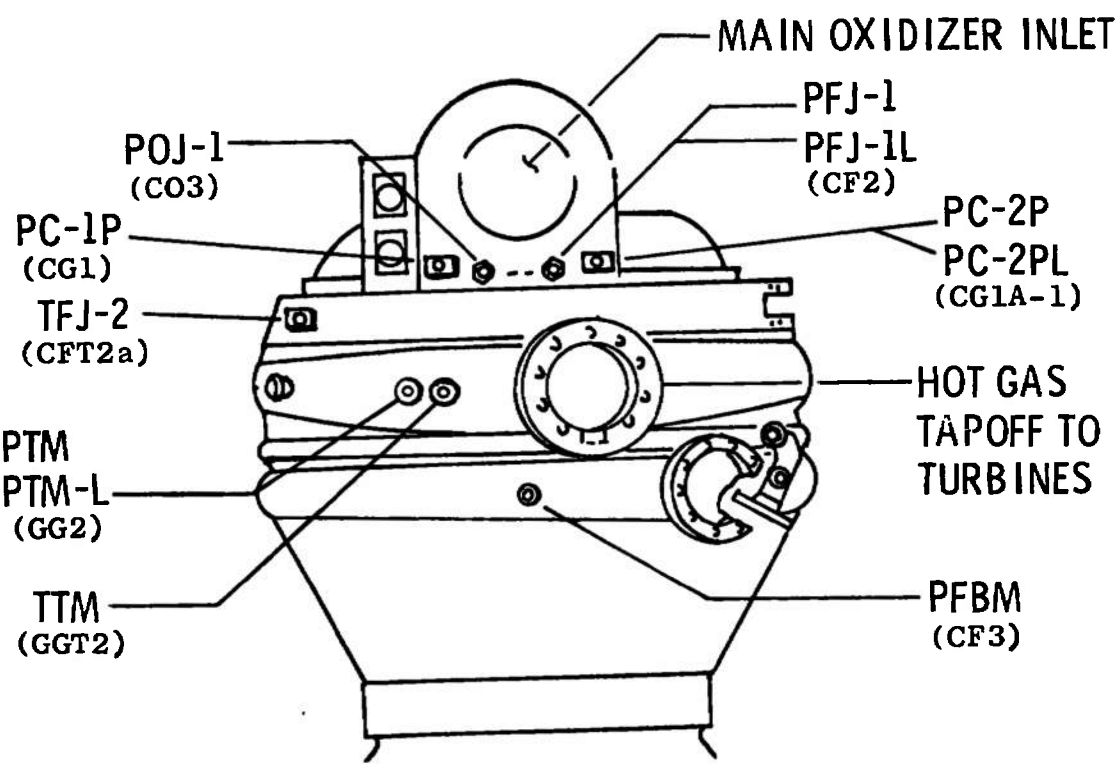

e. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued

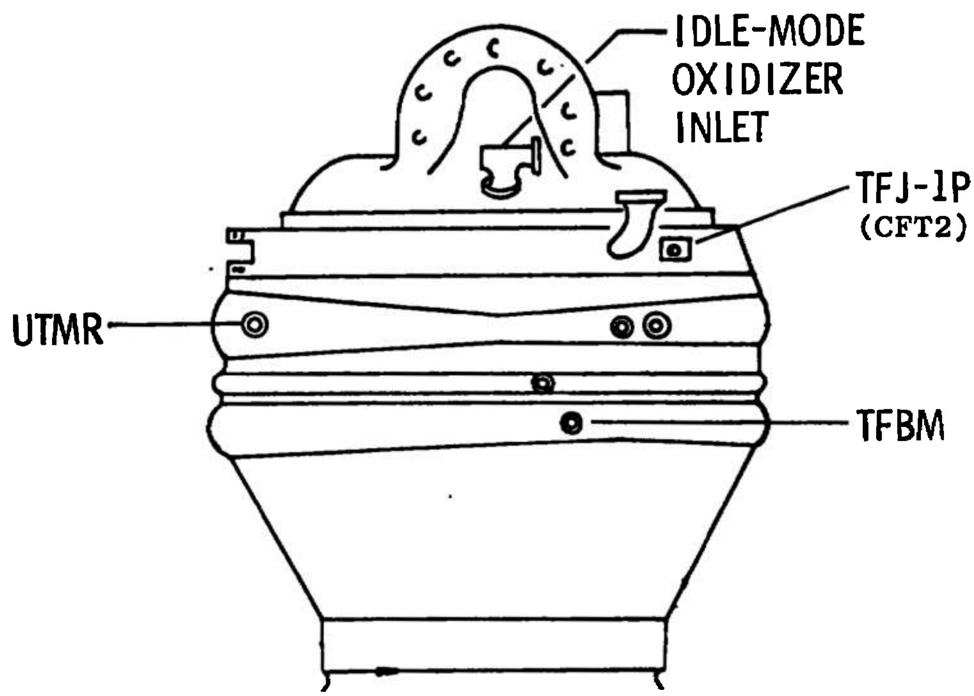



f. Oxidizer System Sensor Locations
Fig. III-1 Continued

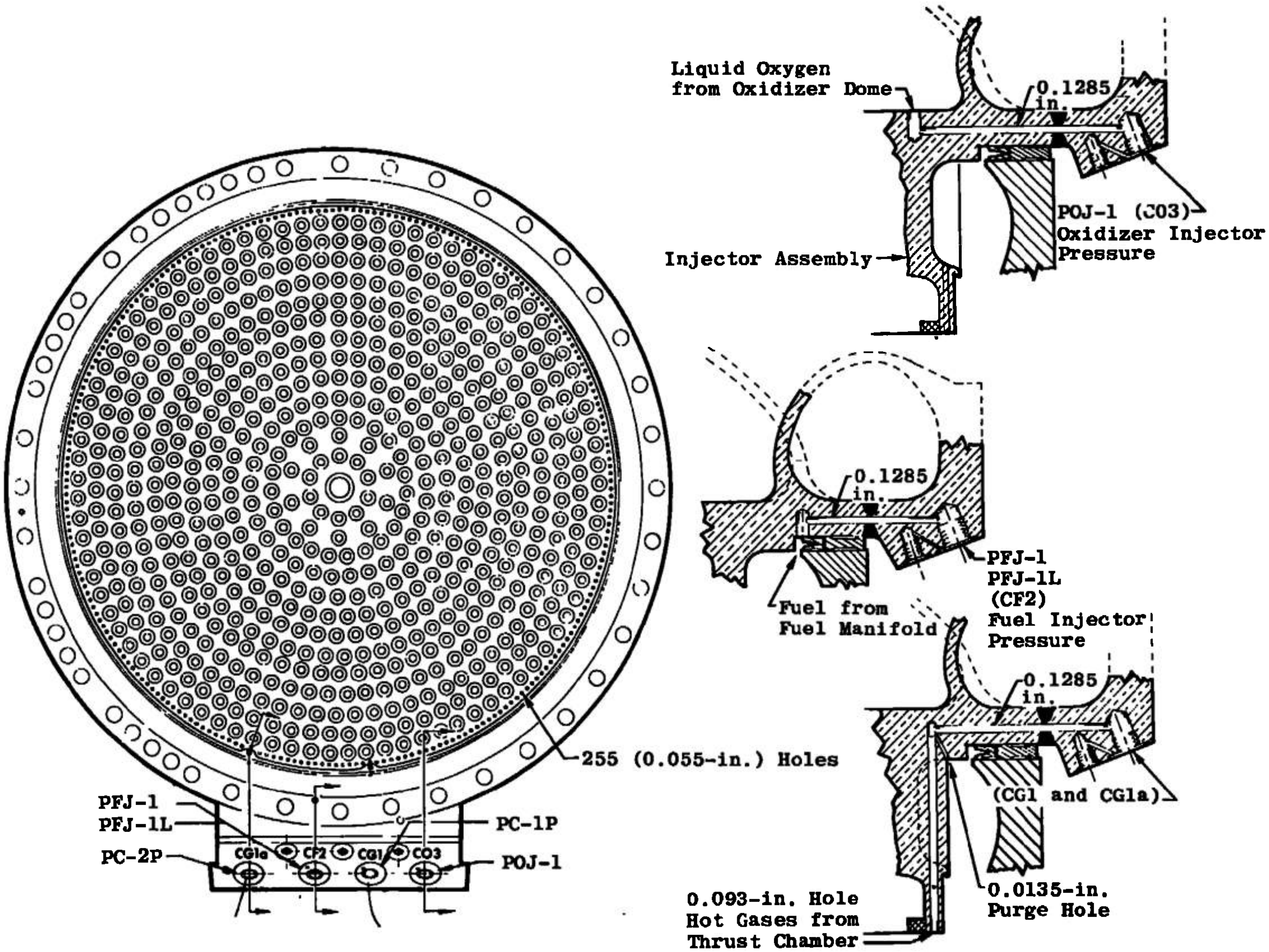



g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



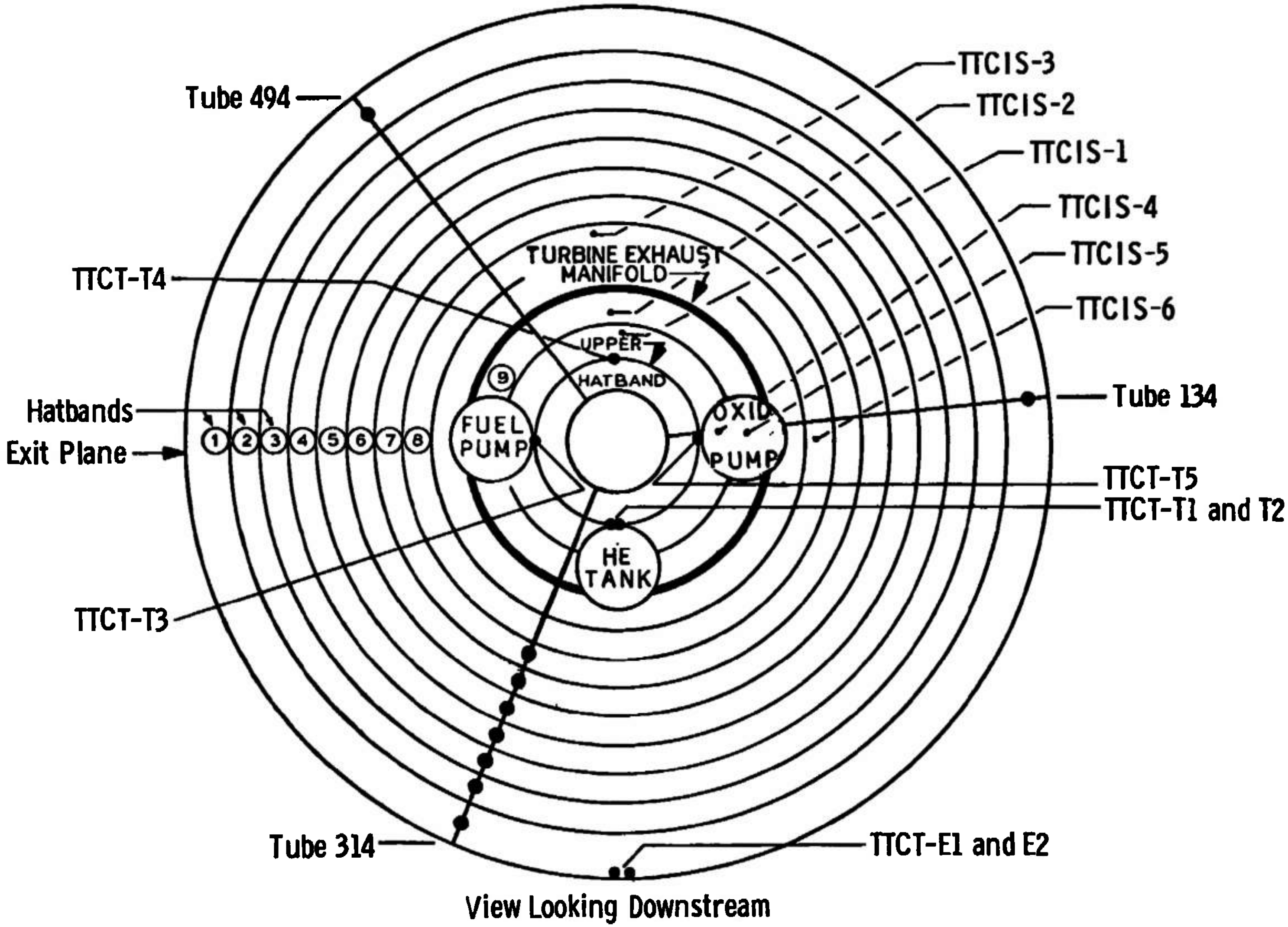




h. Thrust Chamber Sensor Locations
Fig. III-1 Continued

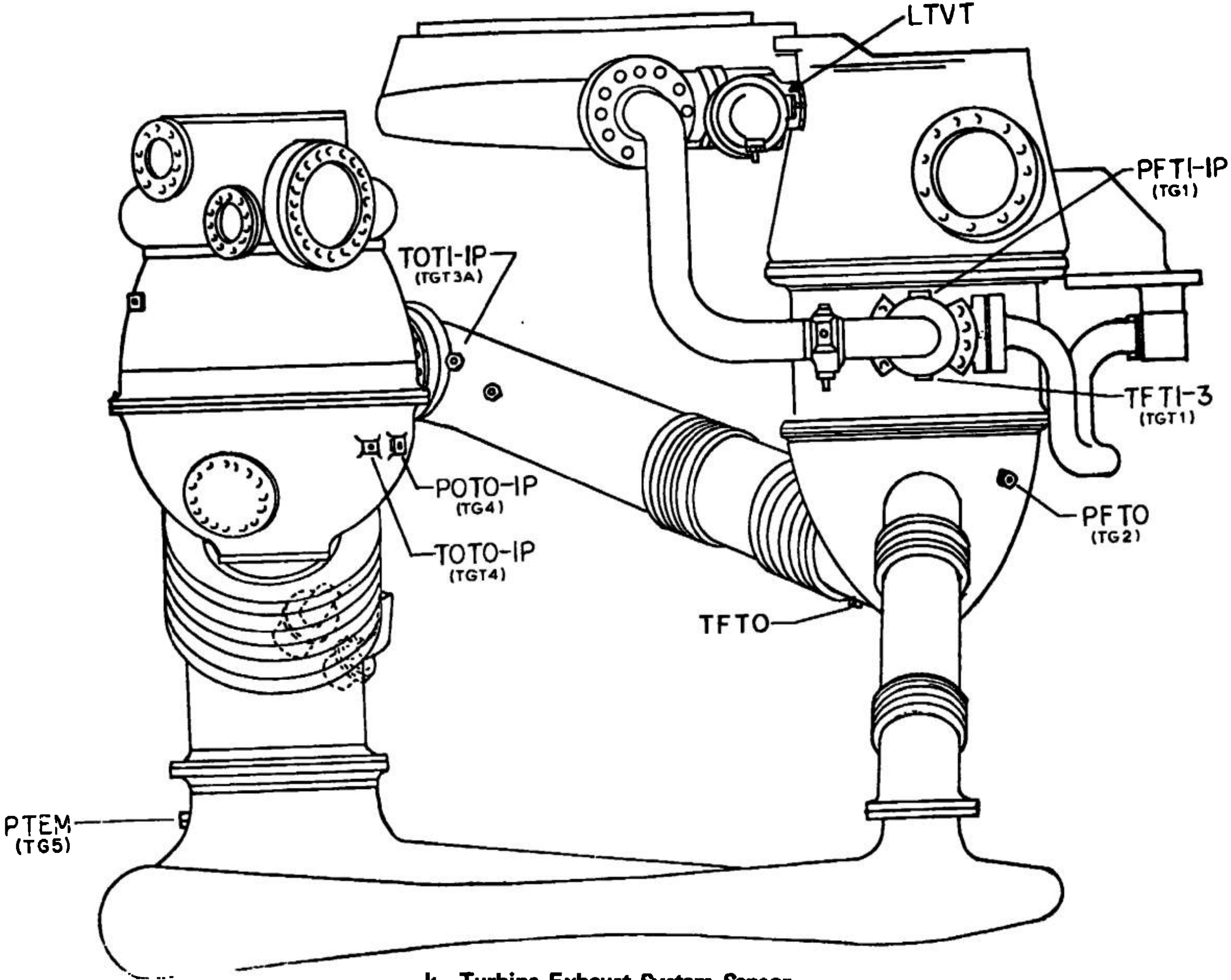



i. Thrust Chamber Injector Sensor Locations

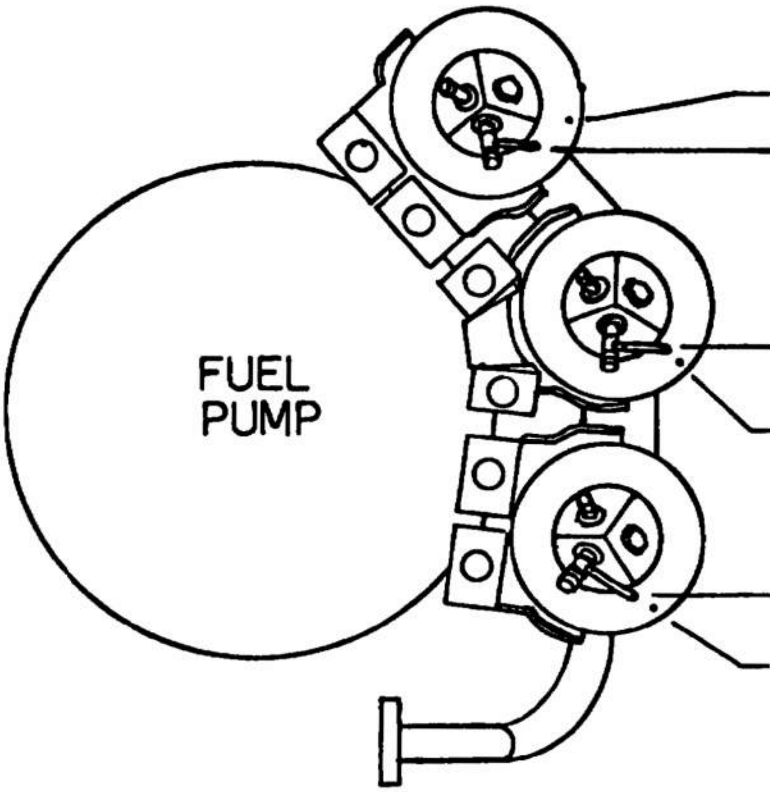
Fig. III-1 Continued

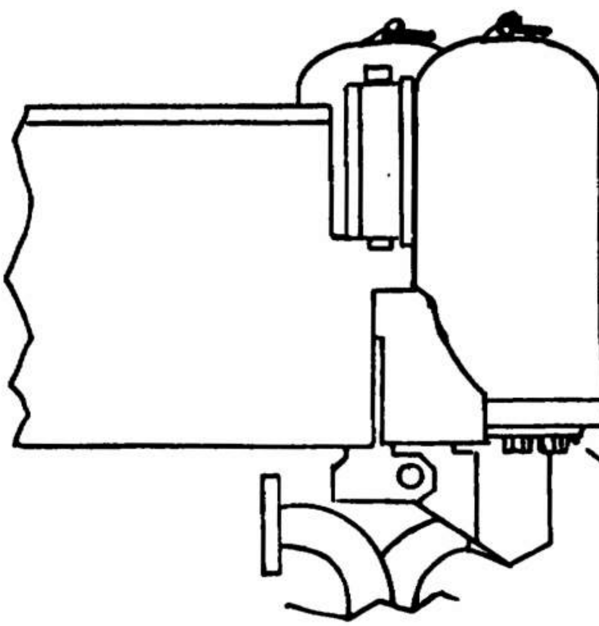



j. Thrust Chamber Sensor Locations

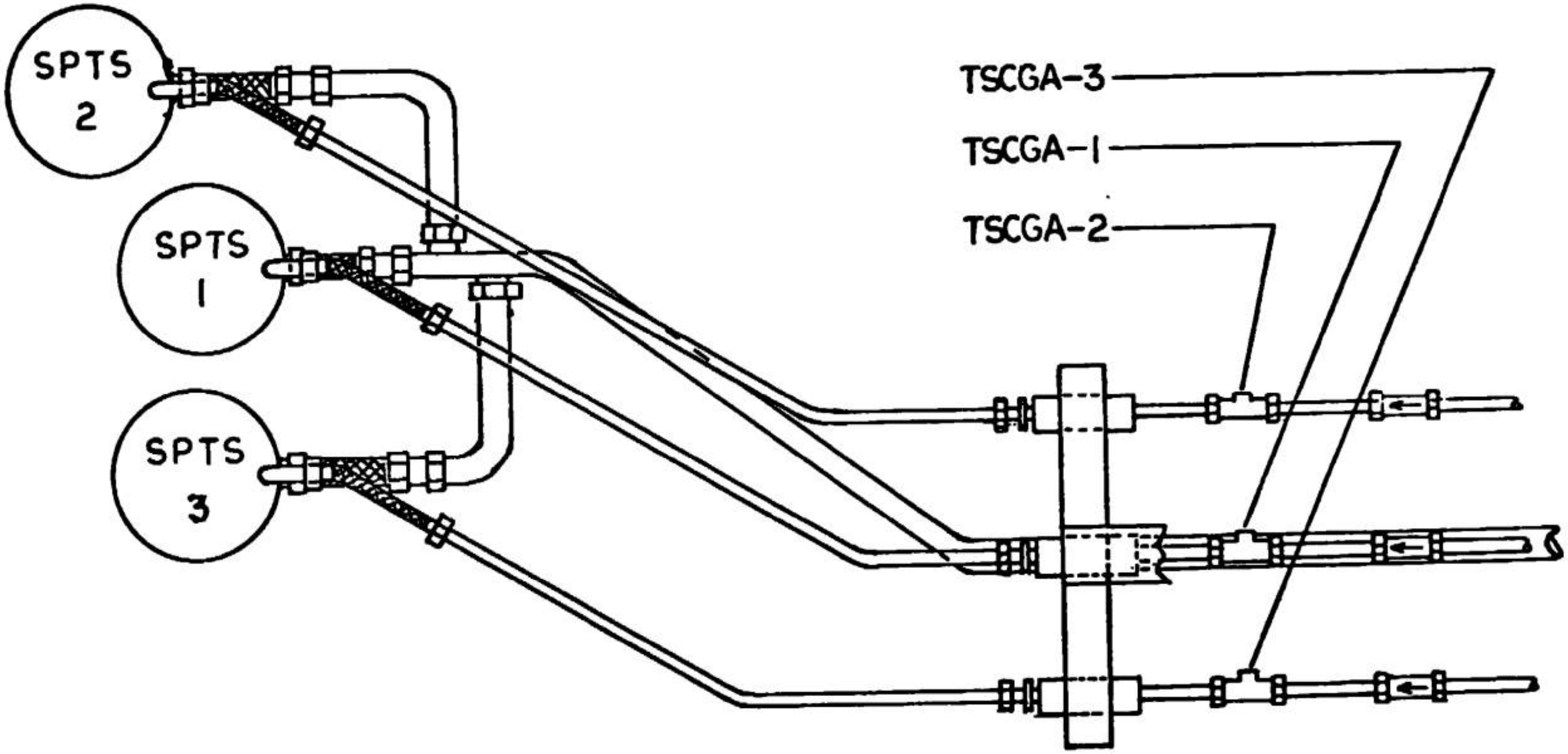



k. Turbine Exhaust System Sensor
Fig. III-1 Continued

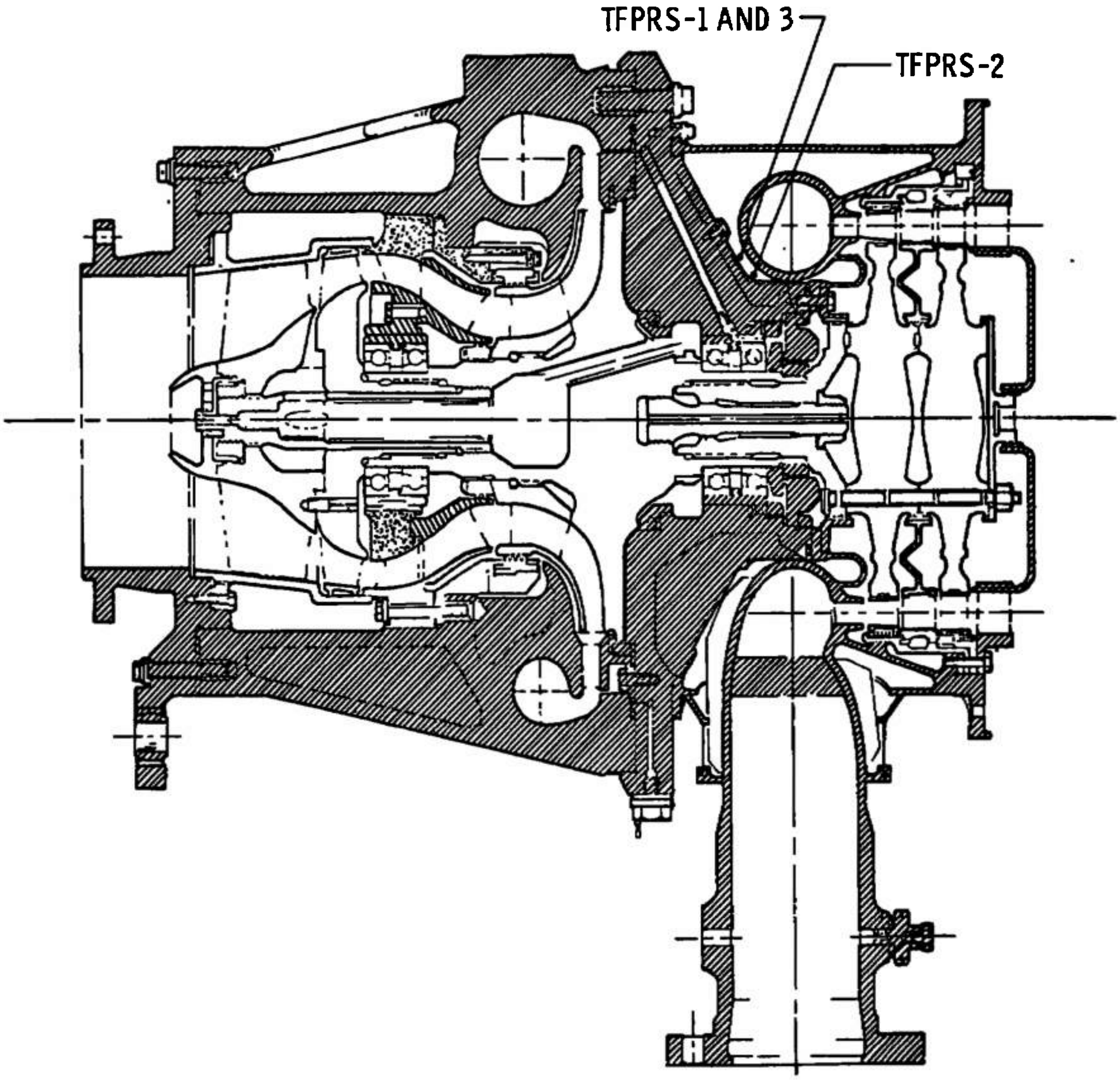


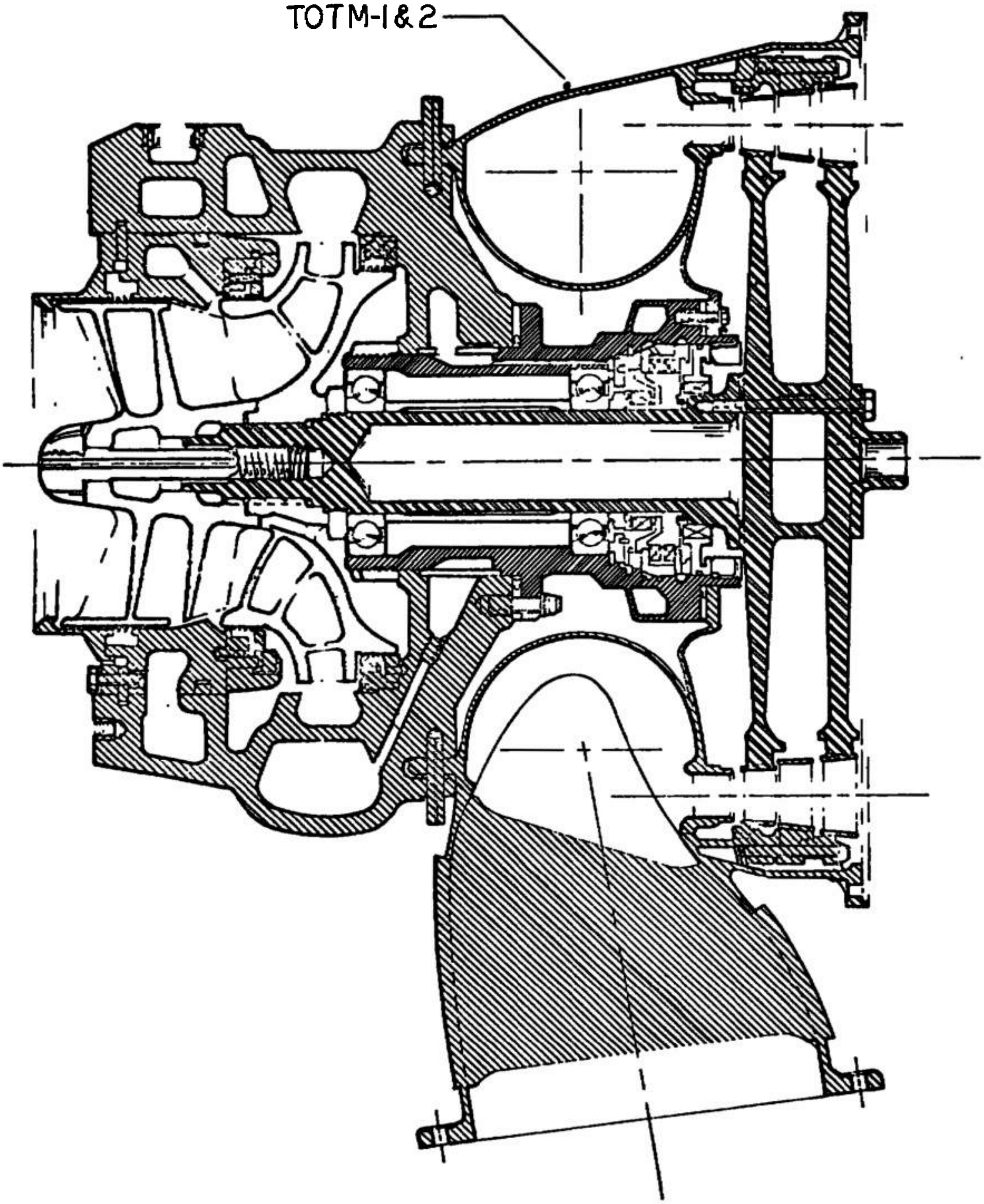

I. Solid-Propellant Turbine Starter Sensor Locations
Fig. III-1 Continued



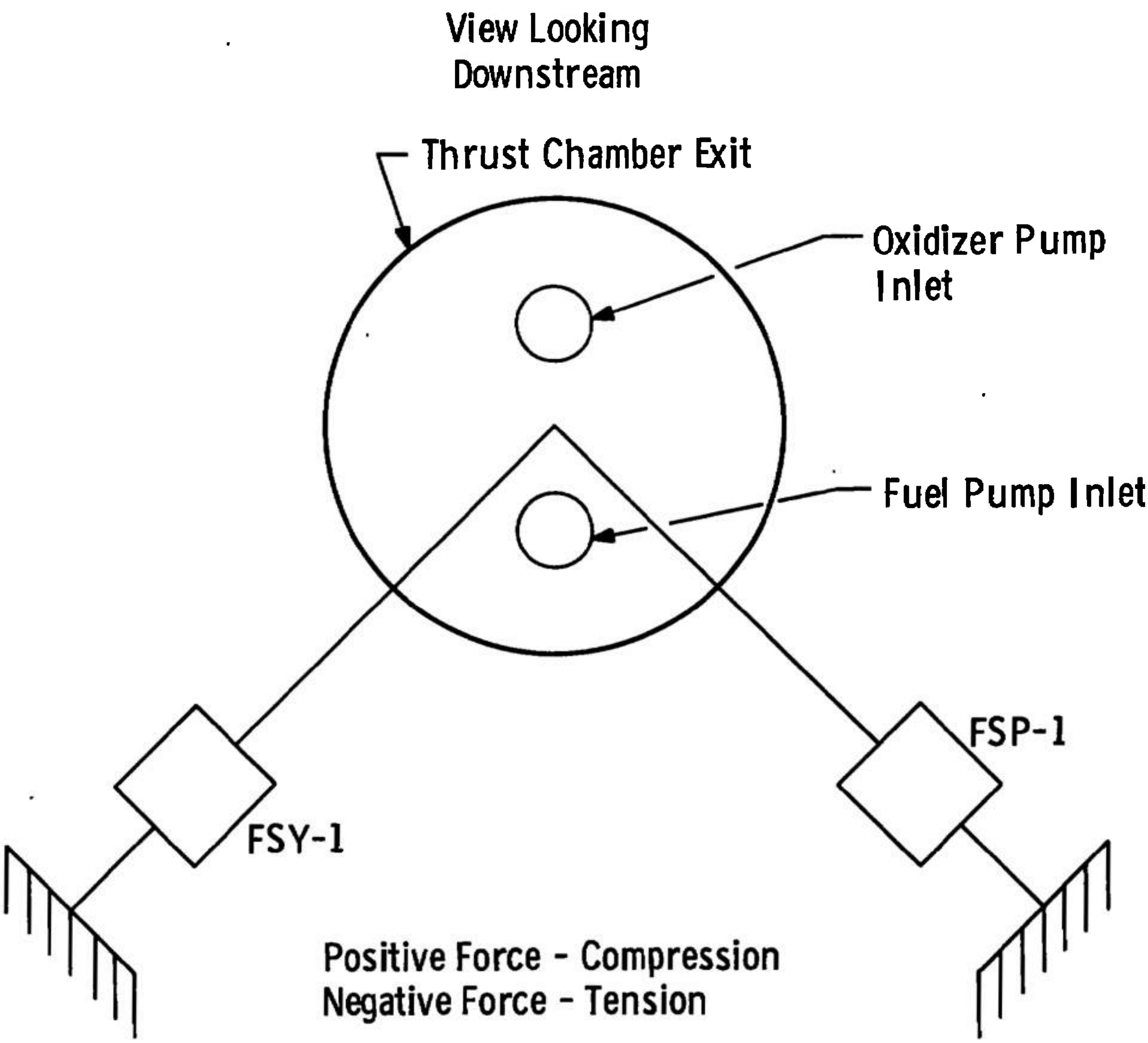

m. Solid-Propellant Turbine Starter Conditioning System Sensor Locations
Fig. III-1 Continued



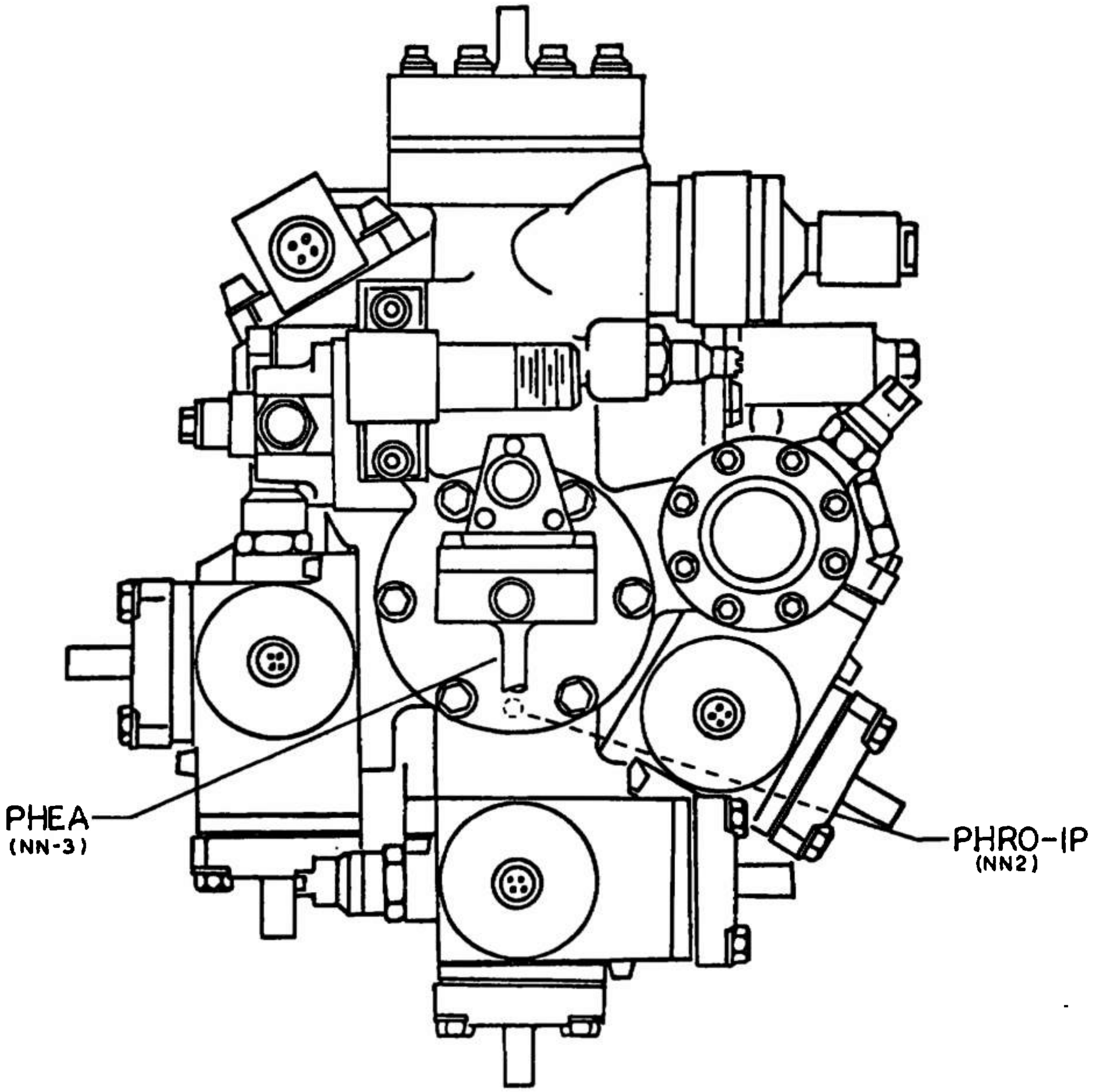

n. Fuel Turbine Sensor Locations
Fig. III-1 Continued



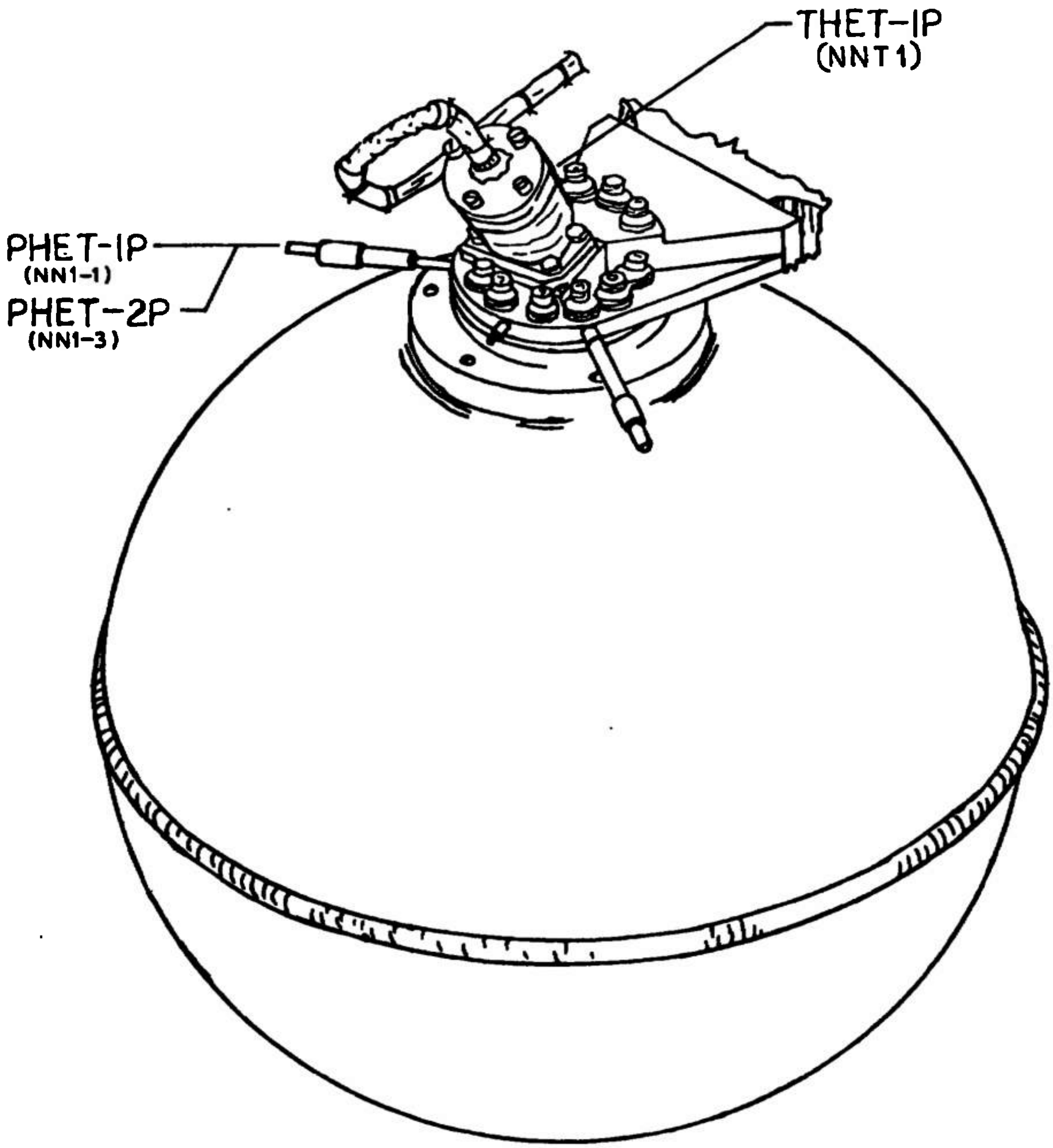

o. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



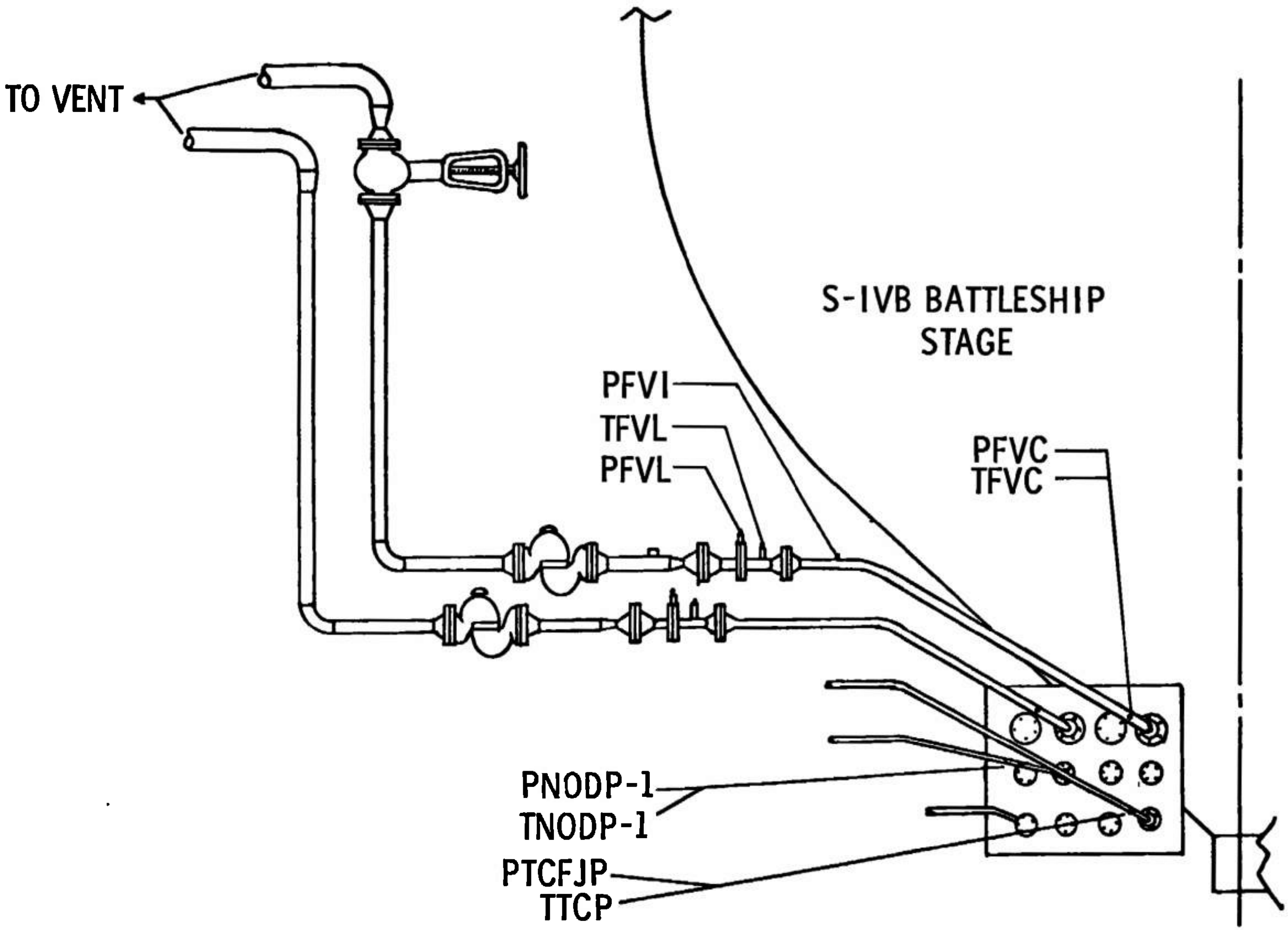

p. Side Load Forces Sensor Locations
Fig. III-1 Continued



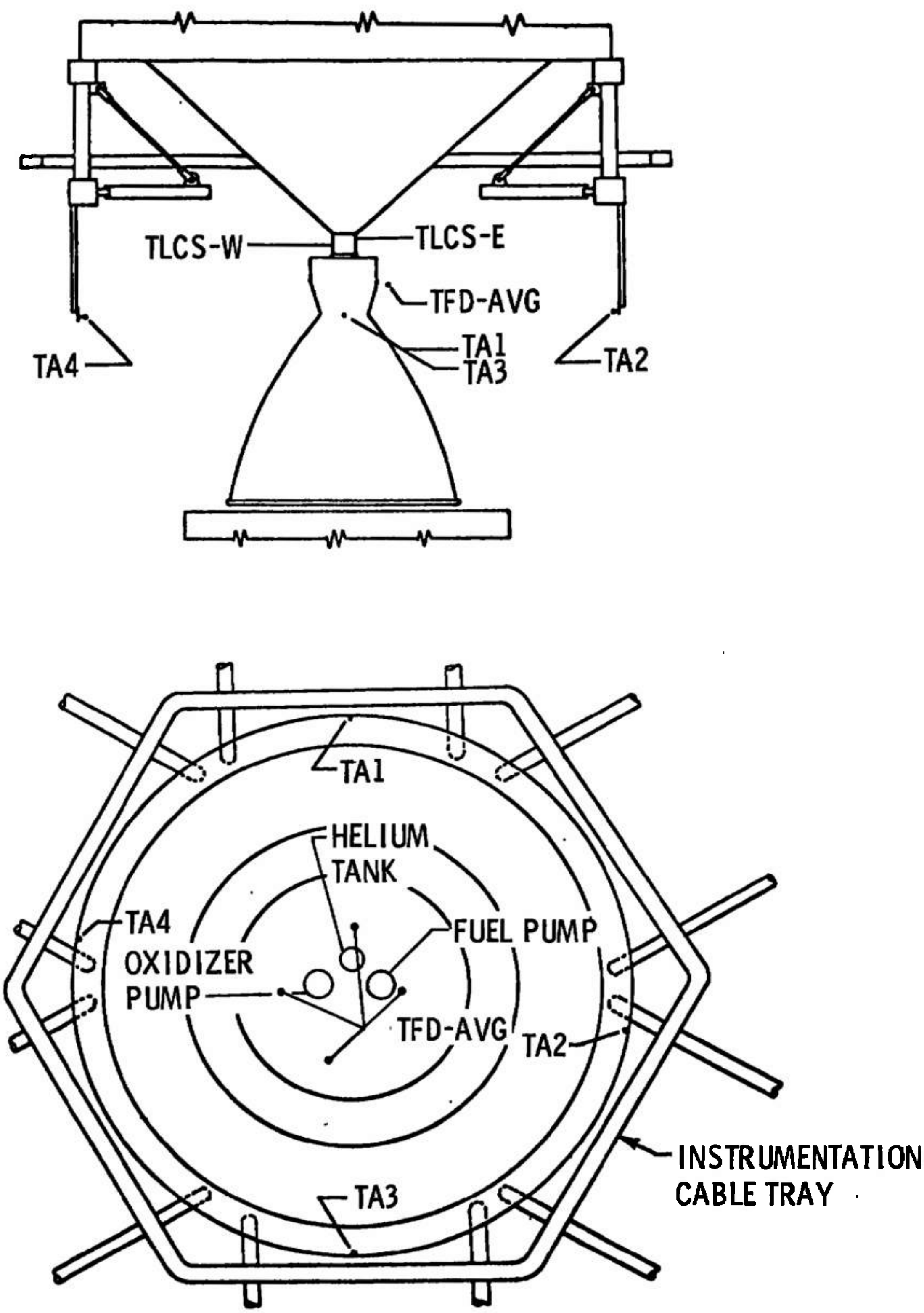

q. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



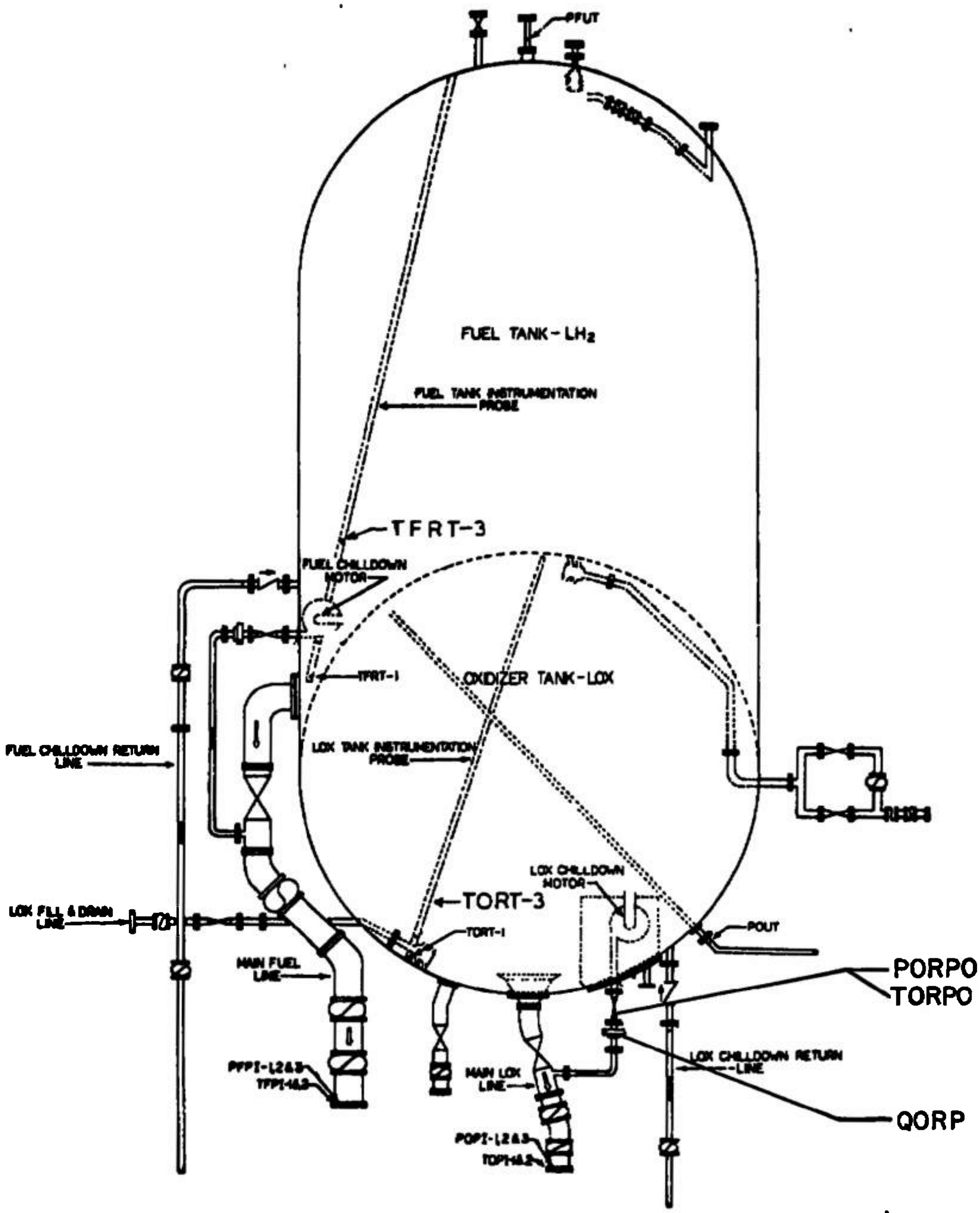

r. Helium Tank Sensor Locations
Fig. III-1 Continued




**s. Customer Connect Panel Sensor Locations**
**Fig. III-1 Continued**




t. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued




u. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

# TABLE III-1
# INSTRUMENTATION LIST

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillo-graph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | Current, amp | | | | | | | | |
| ICC | Control | | 0 to 30 | x | | | | | |
| IIC | Ignition | | 0 to 30 | x | | | | | |
| | Event | | | | | | | | |
| EASIS-1 | Augmented Spark Igniter Spark -1 | | On/Off | | | | | x | |
| EASIS-2 | Augmented Spark Igniter Spark -2 | | On/Off | | | | | x | |
| EECL | Engine Cutoff Lockin | | On/Off | x | | x | | x | |
| EECO | Engine Cutoff Signal | | On/Off | x | | x | | x | |
| EER | Engine Ready Signal | | On/Off | | | | | x | |
| EES | Engine Start Command | | On/Off | x | | x | | x | |
| EESCO | Programmed Duration Cutoff | | On/Off | | | | | x | |
| EFPCO | Fuel Pump Overspeed Cutoff | | On/Off | | | | | x | |
| EFPVC | Fuel Prevalve Closed Limit | | On/Off | x | | | | x | |
| EFPVO | Fuel Prevalve Open Limit | | On/Off | x | | | | x | |
| EFUA | Exploding Bridgewire Firing Units Armed | | On/Off | | | | | x | |
| EHCS | Helium Control Solenoid Energized | | On/Off | x | x | x | | x | |
| EHGTC | Hot Gas Tapoff Valve Closed Limit | | On/Off | | | | | x | |
| EHGTO | Hot Gas Tapoff Valve Open Limit | | On/Off | | | | | x | |
| EID | Ignition Detected | | On/Off | x | | x | | x | |
| EIDA-1 | Ignition Detect Amplifier -1 | | On/Off | | | | | x | |
| EIDA-2 | Ignition Detect Amplifier -2 | | On/Off | | | | | x | |
| EIMCS | Idle-Mode Control Solenoid Energized | | On/Off | x | | x | | x | |
| EIMVC | Idle-Mode Valve Closed Limit | | On/Off | | | | | x | |
| EIMVO | Idle-Mode Valve Open Limit | | On/Off | | | | | x | |
| EMCL | Main-Stage Cutoff Lockin | | On/Off | x | | x | | x | |
| EMCO | Main-Stage Cutoff Signal | | On/Off | x | | x | | | |
| EMCS | Main-Stage Control Solenoid Energized | | On/Off | x | | x | | x | |
| EMD-1 | Main-Stage "OK" Depressurized -1 | | On/Off | x | | x | | x | |
| EMD-2 | Main-Stage "OK" Depressurized -2 | | On/Off | x | | x | | x | |
| EMFVC | Main Fuel Valve Closed Limit | | On/Off | | | | | x | |
| EMFVO | Main Fuel Valve Open Limit | | On/Off | | | | | x | |
| EMOVC | Main Oxidizer Valve Closed Limit | | On/Off | | | | | x | |
| EMOVO | Main Oxidizer Valve Open Limit | | On/Off | | | | | x | |
| EMP-1 | Main-Stage "OK" Pressurized -1 | | On/Off | x | | x | | x | |
| EMP-2 | Main-Stage "OK" Pressurized -2 | | On/Off | x | | | | x | |
| EMPCO | Main-Stage Pressure Cutoff Signal | | On/Off | | | | | x | |
| EMS | Main-Stage Start Signal | | On/Off | | | | | x | |
| EMSCO | Main-Stage Programmed Duration Cutoff | | On/Off | | | | | x | |
| EMSS | Main-Stage Start Solenoid Energized | | On/Off | x | x | x | | x | |

# TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillo-graph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Event** | | | | | | | | |
| EOCO | Observer Cutoff Signal | | On/Off | | | | | x | |
| EOPCO | Oxidizer Pump Overspeed Cutoff Signal | | On/Off | | | | | x | |
| EOPVC | Oxidizer Prevalve Closed Limit | | On/Off | x | | | | x | |
| EOPVO | Oxidizer Prevalve Open Limit | | On/Off | x | | | | x | |
| EOTCO | Fuel Turbine Over-Temperature Cutoff | | On/Off | | | | | x | |
| ERASIS-1 | Augmented Spark Igniter Spark Rate -1 | | On/Off | | | x | | | |
| ERASIS-2 | Augmented Spark Igniter Spark Rate -2 | | On/Off | | | x | | | |
| ES1M1 | No. 1 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 1 | | On/Off | x | | x | | | |
| ES1M2 | No. 1 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 2 | | On/Off | x | | x | | | |
| ES2M1 | No. 2 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 1 | | On/Off | x | | x | | | |
| ES2M2 | No. 2 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 2 | | On/Off | x | | x | | | |
| ES3M1 | No. 3 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 1 | | On/Off | x | | x | | | |
| ES3M2 | No. 3 Solid-Propellant Turbine Starter Exploding Bridge Wire Monitor 2 | | On/Off | x | | x | | | |
| ESAMCO | Stall Approach Monitor Cutoff | | On/Off | | | | | x | |
| ESPTS | Solid-Propellant Turbine Starter Initiated | | On/Off | | | | | x | |
| ESR-1 | Solid-Propellant Turbine Starter 1 Ready | | On/Off | x | | x | | x | |
| ESR-2 | Solid-Propellant Turbine Starter 2 Ready | | On/Off | x | | x | | x | |
| ESR-3 | Solid-Propellant Turbine Starter 3 Ready | | On/Off | x | | x | | x | |
| ESTCO | Start "OK" Timer Cutoff Signal | | On/Off | | | | | x | |
| ETCBC | Thrust Chamber Bypass Valve Closed | | On/Off | | | | | x | |
| ETCBO | Thrust Chamber Bypass Valve Open | | On/Off | | | | | x | |
| EVSC-1 | Vibration Safety Counts -1 | | On/Off | | | x | | | |
| EVSC-2 | Vibration Safety Counts -2 | | On/Off | | | x | | | |
| EVSC-3 | Vibration Safety Counts -3 | | On/Off | | | x | | | |
| | **Flows, gpm** | | | | | | | | |
| QF-1 | Engine Fuel | PFF | 0 to 11,000 | x | | | | | |
| QF-2 | Engine Fuel | PFFa | 0 to 11,000 | x | x | x | | | x |
| QF-3 | Engine Fuel | PFF | 0 to 11,000 | | | x | | | |
| QF-1SAM (2) | Stall Approach Monitor | | 0 to 370 | x | | x | | | |
| QO-1 | Engine Oxidizer | POF | 0 to 3,600 | x | | | | | |
| QO-2 | Engine Oxidizer | POFa | 0 to 3,600 | x | x | x | | | |
| QO-3 | Engine Oxidizer | POF | 0 to 3,600 | | | x | | | |
| QORP (1) | Oxidizer Recirculation System | | 0 to 50 | x | x | x | | | |

# TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillograph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Forces, lbf** | | | | | | | | |
| FSP-1 | Side Load (Pitch) | | ±20,000 | x | x | x | | | |
| FSY-1 | Side Load (Yaw) | | ±20,000 | x | x | x | | | |
| FZ-H | Axial Thrust | | 0 to 300,000 | x | x | x | | | |
| FZ-L | Axial Thrust | | ±10,000 | x | x | x | | | |
| | **Position, Percent Open** | | | | | | | | |
| LFBT | Thrust Chamber Bypass Valve | | 0 to 100 | x | | x | | | |
| LFVT | Main Fuel Valve | | 0 to 100 | x | | x | | | |
| LIMT | Idle Mode/Augmented Spark Igniter Oxidizer Valve | | 0 to 100 | x | | x | | | |
| LOVT | Main Oxidizer Valve | | 0 to 100 | x | | x | | | |
| LPUTOP | Propellant Utilization Valve | | 5 volts | x | | x | x | | |
| LTVT | Hot Gas Tapoff Valve | | 0 to 100 | x | | x | | | |
| | **Pressure, psia** | | | | | | | | |
| PA-1 | Test Cell | | 0 to 0.5 | x | | | | | |
| PA-2 | Test Cell | | 0 to 1.0 | x | | | | | |
| PA-3 | Test Cell | | 0 to 5.0 | x | | x | x | | |
| PC-1P | Thrust Chamber | CG1 | 0 to 1500 | x | | | | | |
| PC-2P | Thrust Chamber | CG1a | 0 to 1500 | x | | x | x | | |
| PC-2PL | Thrust Chamber | CG1a-1 | 0 to 50 | x | | x | x | | |
| PCSPTS-1 | Solid-Propellant Turbine Starter Chamber 1 | PTS-1 | 0 to 5000 | x | | x | | | |
| PCSPTS-2 | Solid-Propellant Turbine Starter Chamber 2 | PTS-2 | 0 to 5000 | x | | x | | | |
| PCSPTS-3 | Solid-Propellant Turbine Starter Chamber 3 | PTS-3 | 0 to 5000 | x | | x | | | |
| PFBM | Thrust Chamber Bypass Manifold | CF3 | 0 to 1500 | x | | | | | |
| PFCO | Film Coolant Orifice | CF4 | 0 to 2000 | x | | | | | |
| PFCO-L | Film Coolant Orifice | CF4 | 0 to 50 | x | | | | | |
| PFCVI | Film Coolant Venturi Inlet | CF7 | 0 to 2000 | x | | | | | |
| PFCVI-L | Film Coolant Venturi Inlet | CF7 | 0 to 50 | x | | | | | |
| PFCVT | Film Coolant Venturi Throat | CF6 | 0 to 2000 | x | | | | | |
| PFCVT-L | Film Coolant Venturi Throat | CF6 | 0 to 50 | x | | | | | |
| PFJ-1 | Fuel Injection | CF2 | 0 to 1500 | x | | x | | | |
| PFJ-1L | Fuel Injection | CF2 | 0 to 50 | x | | | | | |
| PFMI | Fuel Jacket Manifold Inlet | CF1 | 0 to 2000 | x | | | | | |
| PFMI-L | Fuel Jacket Manifold Inlet | CF1 | 0 to 50 | | | | | | |
| PFPBC | Fuel Pump Balance Piston Cavity | PF5 | 0 to 2000 | x | | x | x | | |
| PFPBS | Fuel Pump Balance Piston Sump | PF4 | 0 to 1000 | x | | x | x | | |
| PFPD-1L | Fuel Pump Discharge | PF3 | 0 to 50 | x | | | | | |
| PFPD-1P | Fuel Pump Discharge | PF3 | 0 to 2500 | x | x | x | x(3) | | x |
| PFPI-1 | Fuel Pump Inlet | PF1 | 0 to 100 | x | | | x(3) | | x |
| PFPI-2 | Fuel Pump Inlet | | 0 to 100 | x | | | | | x |
| PFPI-3 | Fuel Pump Inlet | PF1a | 0 to 100 | x | x | x | | | x |
| PFPRB | Fuel Pump Rear Bearing Coolant | PF7 | 0 to 1000 | x | | | | | |
| PFPS | Fuel Pump Interstage | PF6 | 0 to 1000 | x | | x | x(3) | | |

# TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillograph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Pressure, psia** | | | | | | | | |
| PFPSI | Fuel Pump Shroud Inlet | | 0 to 3500 | x | | | x (3) | | |
| PFTI-1P | Fuel Turbine Inlet | TG1 | 0 to 1000 | x | | x | | | |
| PFTO | Fuel Turbine Outlet | TG2 | 0 to 200 | x | | | | | |
| PFTSC | Fuel Turbine Seal Cavity | TG10 | 0 to 500 | x | | | | | |
| PFUT | Fuel Ullage Tank | | 0 to 100 | x | | | | | |
| PFVC | Fuel Repressurization at Customer Connect Panel | | 0 to 2000 | x | | | | | |
| PFVI | Fuel Repressurization Nozzle Inlet | KHF1 | 0 to 2000 | x | | | | | |
| PFVL | Fuel Repressurization Nozzle Throat | KHF2 | 0 to 1000 | x | | | | | |
| PHEA | Helium Accumulator | HN3 | 0 to 750 | x | | | | | |
| PHECMO | Helium Control Module | | 0 to 750 | x | | | | | |
| PHES | Helium Supply | | 0 to 5000 | x | | | | | |
| PHET-1P | Helium Tank | HN1-1 | 0 to 5000 | x | | | | | x |
| PHET-2P | Helium Tank | HN1-3 | 0 to 5000 | x | | | | | |
| PHRO-1P | Helium Regulator Outlet | HN2 | 0 to 750 | x | | | | | |
| PNODP-1 | Oxidizer Dome Purge at Customer Connect Panel | | 0 to 750 | x | | | | | |
| PNODP-2 | Oxidizer Dome Purge at Customer Connect Panel | | 0 to 1500 | x | | | | | |
| POASIJ | Augmented Spark Igniter Oxidizer Injection | IO3 | 0 to 1500 | x | | x | | | |
| POIML | Oxidizer Idle-Mode Line | PO10 | 0 to 2000 | | x | | | | |
| POIML-L | Oxidizer Idle-Mode Line | PO10 | 0 to 50 | | x | | | | |
| POJ-1 | Oxidizer Injection | CO3 | 0 to 1500 | x | | | | | |
| POJ-2 | Oxidizer Injection | CO3a | 0 to 1500 | x | | x | | | |
| POJ-2L | Oxidizer Injection | CO3a | 0 to 50 | x | | x (6) | | | |
| POJ-3 | Oxidizer Injection Manifold | CO3b | 0 to 2000 | | x | x | | | |
| POPBC | Oxidizer Pump Bearing Coolant | PO7 | 0 to 500 | x | | | | | |
| POPD-1L | Oxidizer Pump Discharge | PO3 | 0 to 50 | x | | | | | |
| POPD-1P | Oxidizer Pump Discharge | PO3 | 0 to 2500 | x | | | | | |
| POPD-2 | Oxidizer Pump Discharge | PO2 | 0 to 3500 | x | x | x | | | |
| POPI-1 | Oxidizer Pump Inlet | PO1 | 0 to 100 | x | | | | | x |
| POPI-2 | Oxidizer Pump Inlet | | 0 to 100 | x | | | | | x |
| POPI-3 | Oxidizer Pump Inlet | PO1a | 0 to 100 | x | x | x | | | |
| POPSC | Oxidizer Pump Primary Seal Cavity | PO6 | 0 to 50 | x | | | | | |
| PORPO (1) | Oxidizer Recirculation Pump Outlet | | 0 to 100 | x | | | | | |
| POTI-1P | Oxidizer Turbine Inlet | TG3 | 0 to 200 | x | | | | | |
| POTO-1P | Oxidizer Turbine Outlet | TG4 | 0 to 100 | x | | | | | |
| POUT | Oxidizer Ullage Tank | | 0 to 100 | x | | | | | |
| PPTD | Photocon Cooling Water (Downstream) | | 0 to 100 | x | | | | | |
| PPTU | Photocon Cooling Water (Upstream) | | 0 to 100 | x | | | | | |
| PPUVI | Propellant Utilization Valve Inlet | PO8 | 0 to 2000 | x | | | | | |

# TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillograph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Pressure, psia** | | | | | | | | |
| PPUVO | Propellant Utilization Valve Outlet | PO9 | 0 to 1000 | x | | | | | |
| PTCFJP | Thrust Chamber Fuel Jacket Purge | | 0 to 200 | x | | | | | |
| PTEM | Turbine Exhaust Manifold | TG5 | 0 to 50 | x | | | | | |
| PTM | Tapoff Manifold | GGT2 | 0 to 1500 | x | | | | | |
| PTM-L | Tapoff Manifold | GG2 | 0 to 50 | x | | x[6] | | | |
| | **Speeds, rpm** | | | | | | | | |
| NFP-1 | Fuel Pump | PFV | 0 to 33000 | | x | x[2] | | | |
| NFP-2 | Fuel Pump | PFV | 0 to 33000 | x | | | | | |
| NFP-3 | Fuel Pump | PFV | 0 to 33000 | | | x | | | |
| NOP-1 | Oxidizer Pump | POV | 0 to 12000 | | x | | | | |
| NOP-2 | Oxidizer Pump | POV | 0 to 12000 | x | | | | | |
| NOP-3 | Oxidizer Pump | POV | 0 to 12000 | | | x | | | |
| | **Temperatures, °F** | | | | | | | | |
| TA-1 | Test Cell, North | | -50 to 800 | x | | | | | |
| TA-2 | Test Cell, East | | -50 to 800 | x | | | | | |
| TA-3 | Test Cell, South | | -50 to 800 | x | | | | | |
| TA-4 | Test Cell, West | | -50 to 800 | x | | | | | |
| TECP-1P | Electrical Control Assembly | NST1a | -300 to 200 | x | | | | | |
| TFASIJ[3] | Augmented Spark Igniter Fuel Injection | IFT | -425 to 100 | x | | x | | | |
| TFBMTT[4] | Thrust Chamber Bypass Manifold | GG2b | -440 to 500 | x | | | | | |
| TFCO | Film Coolant Orifice | IFT1 | -440 to 500 | x | | | | | |
| TFD-Avg | Fire Detection | | 0 to 1000 | x | | | x | | |
| TFDFTA | Fire Detect Fuel Turbine Manifold Area | | 0 to 500 | x | | | | | |
| TFDMFVA | Fire Detect Main Fuel Valve Area | | 0 to 500 | x | | | | | |
| TFDMOVA | Fire Detect Main Oxidizer Valve Area | | 0 to 500 | x | | | | | |
| TFDODA | Fire Detect Oxidizer Dome Area | | 0 to 500 | x | | | | | |
| TFDTDA | Fire Detect Tapoff Duct Area | | 0 to 500 | x | | | | | |
| TFJ-1P | Fuel Injection | CFT2 | -425 to -300 | x | | | | | |
| TFJ-2P | Fuel Injection | CFT2a | -425 to 100 | x | | x | x | | |
| TFPBS | Fuel Pump Balance Piston Sump | PFT4 | -425 to 100 | x | | | x[2] | | |
| TFPD-1P | Fuel Pump Discharge | PFT1 | -425 to -900 | x | x | | | | |
| TFPD-2P | Fuel Pump Discharge | PFT1 | -425 to 100 | x | | | | | |
| TFPD-3 | Fuel Pump Discharge | PF3 | -425 to -390 | x | | | | | |
| TFPD-4 | Fuel Pump Discharge | PF3 | -425 to 100 | x | | | | | |
| TFPI-1 | Fuel Pump Inlet | XFT2 | -425 to -400 | x | | | | | x |
| TFPI-2 | Fuel Pump Inlet | XFT2a | -425 to 100 | x | | | | | x |
| TFPRS-1 | Fuel Pump Rear Support | | -400 to 1800 | x | | | | | |
| TFPRS-2 | Fuel Pump Rear Support | | -400 to 1800 | x | | | | | |
| TFPRS-3 | Fuel Pump Rear Support | | -400 to 1800 | x | | | | | |
| TFRT-1 | Fuel Run Tank | | -425 to -400 | x | | | | | |
| TFRT-3 | Fuel Run Tank | | -425 to -400 | x | | | | | |
| TFTI-3 | Fuel Turbine Inlet | TGT1 | -300 to 2400 | x | | | x | | |
| TFTI-4 | Fuel Turbine Inlet | | -300 to 2000 | x | | | | | |
| TFTO | Fuel Turbine Outlet | | -100 to 1200 | x | | | | | |

# TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillograph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Temperature, °F** | | | | | | | | |
| TFVC | Fuel Repressurization at Customer Connect Panel | | -300 to -100 | x | | | | | |
| TFVL | Fuel Repressurization Nozzle Inlet | KHFT1 | -300 to -100 | • | | | | | |
| THET-1P | Helium Tank | NNT1 | -200 to 300 | x | | | | | • |
| TLCS-E[2] | Load Cell Surface East | | -240 to 300 | • | | | | | |
| TLCS-N[2] | Load Cell Surface North | | -240 to 300 | • | | | | | |
| TMFVS-1 | Main Fuel Valve Skin (Outer Wall) | | -425 to 100 | • | | | • | | |
| TMFVS-2 | Main Fuel Valve Skin (Inner Wall) | | -425 to 100 | • | | | • | | |
| TMODP-1 | Oxidizer Dome Purge at Customer Connect Panel | | -250 to 200 | • | | | | | |
| TMODP-2 | Oxidizer Dome Purge at Customer Connect Panel | | -250 to 200 | • | | | | | |
| TOIML | Oxidizer Idle Mode Line | POT5 | -300 to 100 | x | | | | | |
| TOJ | Oxidizer Injection | COT1 | -300 to 1200 | • | | • | • (2) | | |
| TOPBC | Oxidizer Pump Bearing Coolant | POT4 | -300 to 1950 | • | | | • | | |
| TOPD-1P | Oxidizer Pump Discharge | POT3 | -300 to -250 | • | | | | | |
| TOPD-2P | Oxidizer Pump Discharge | POT3 | -300 to 100 | • | | | | | |
| TOPDF | Oxidizer Pump Discharge Flange | | -300 to 100 | • | | | | | |
| TOPI-1 | Oxidizer Pump Inlet | KOT2 | -310 to -250 | • | | | | | x |
| TOPI-2 | Oxidizer Pump Inlet | KOT2a | -310 to 100 | • | | | | | • |
| TOPIS[4] | Oxidizer Pump Inlet Seal | | -310 to 100 | • | | | | | |
| TOPVS | Oxidizer Pump Volute Skin | | -300 to 100 | • | | | | | |
| TORPO[1] | Oxidizer Pump Recirculation Outlet | | -300 to -250 | x | | | | | |
| TORT-1 | Oxidizer Run Tank | | -300 to -285 | • | | | | | |
| TORT-3 | Oxidizer Run Tank | | -300 to -285 | x | | | | | |
| TOTI-1P | Oxidizer Turbine Inlet | TGT2 | 0 to 1200 | x | | | | | |
| TOTM-1 | Oxidizer Turbine Manifold | | -300 to 1000 | • | | | | | |
| TOTM-2 | Oxidizer Turbine Manifold | | -300 to 1000 | x | | | | | |
| TOTO-1P | Oxidizer Turbine Outlet | TGT4 | 0 to 1000 | • | | | | | |
| TPIP-1P | Instrumentation Package | | -300 to 200 | x | | | | | |
| TPTU | Photocon Cooling Water (Upstream) | | 0 to 300 | • | | | | | |
| TSCGA-1 | Solid-Propellant Turbine Starter Cond. Gas 1 | | -100 to 300 | • | | | | | |
| TSCGA-2 | Solid-Propellant Turbine Starter Cond. Gas 2 | | -100 to 300 | x | | | | | |
| TSCGA-3 | Solid-Propellant Turbine Starter Cond. Gas 3 | | -100 to 300 | • | | | | | |
| TSCMF-1 | Solid-Propellant Turbine Starter Case Mount Flange | | -300 to 2382 | x | | | | | |
| TSCMF-2 | Solid-Propellant Turbine Starter Case Mount Flange | | -300 to 2382 | x | | | | | |
| TSCMF-3 | Solid-Propellant Turbine Starter Case Mount Flange | | -300 to 2382 | • | | | | | |
| TTCIS-1[2] | Thrust Chamber Internal Skin | | -425 to 100 | x | | | | | |
| TTCIS-2[2] | Thrust Chamber Internal Skin | | -425 to 100 | x | | | | | |
| TTCIS-3[2] | Thrust Chamber Internal Skin | | -425 to 100 | • | | | | | |
| TTCIS-5[2] | Thrust Chamber Internal Skin | | -425 to 100 | x | | | | | |
| TTCIS-6[2] | Thrust Chamber Internal Skin | | -425 to 200 | • | | | | | |
| TTCP | Thrust Chamber Purge | | -250 to 200 | • | | | | | |

# TABLE III-1 (Concluded)

| AEDC Code | Parameter | Tap Number | Range | Digital Data System | Magnetic Tape | Oscillo-graph | Strip Chart | Event Recorder | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|---|
| | **Temperatures, °F** | | | | | | | | |
| TTCT-E1 | Thrust Chamber Tube (Exit) | | -425 to 500 | x | | | | | |
| TTCT-E2 | Thrust Chamber Tube (Exit) | | -425 to 500 | x | | | | | |
| TTCT-T1 | Thrust Chamber Tube (Throat) | | -425 to 500 | x | | | x(5) | | |
| TTCT-T2 | Thrust Chamber Tube (Throat) | | -425 to 500 | x | | | x(2) | | |
| TTCT-T3 | Thrust Chamber Tube (Throat) | | -425 to 500 | x | | | | | |
| TTCT-T4 | Thrust Chamber Tube (Throat) | | -425 to 500 | x | | | | | |
| TTCT-T5 | Thrust Chamber Tube (Throat) | | -425 to 500 | x | | | | | |
| TTM | Tapoff Manifold | | 0 to 2000 | x | | x | x | | |
| | **Peak Vibrations, g** | | | | | | | | |
| UOPR | Oxidizer Pump Radial | PZA-2 | 300 peak | | x | | | | |
| UTCD-1 | Thrust Chamber Dome | PZA-1a | 1400 peak | | x | x | | | |
| UTCD-2 | Thrust Chamber Dome | PZA-2 | 1400 peak | | x | x | | | |
| UTCD-3 | Thrust Chamber Dome | PZA-3 | 300 peak | | x | x | | | |
| UTCD-4 | Thrust Chamber Dome | | 1400 peak | | x | | | | |
| UTCD-5 | Thrust Chamber Dome | | 1400 peak | | x | | | | |
| UTCD-6 | Thrust Chamber Dome | | 1400 peak | | x | | | | |
| UTMR | Tapoff Manifold Radial | | 300 peak | | x | | | | |
| | **Voltage, volts** | | | | | | | | |
| VCB | Control Bus | | 0 to 36 | x | | | | | |
| VIB | Ignition Bus | | 0 to 36 | x | | | | | |
| VIDA-1 | Ignition Detect Amplifier | | 9 to 16 | x | | | | | |
| VIDA-2 | Ignition Detect Amplifier | | 9 to 16 | x | | | | | |
| VPUVEP | Propellant Utilization Valve Telemetry Potentiometer Excitation | | 0 to 5 | x | | | | | |

NOTES:
(1) Required for J4-1001-11 only
(2) Required for J4-1001-15 only
(3) Required for J4-1001-06, 07, and 11 only
(4) Required for J4-1001-06 and 07 only
(5) Required for J4-1001-06, 07, and 15 only
(6) Required for J4-1001-07, 11, and 15 only

# APPENDIX IV
# METHODS OF CALCULATIONS

## NOMENCLATURE

| | |
|---|---|
| A | Area, sq in. |
| C* | Characteristic velocity, ft/sec |
| F | Thrust, lbf |
| g | Gravitational constant, 32.174 lbm-ft/lbf-sec$^2$ |
| I | Impulse, sec |
| MR | Mixture ratio, by weight |
| P | Pressure, psia |
| W | Flow rate, lbm/sec |
| $\rho$ | Density, lbm/cu ft |

## SUBSCRIPTS

| | |
|---|---|
| a | Ambient |
| c | Chamber |
| e | Exit |
| f | Fuel |
| o | Oxidizer |
| sp | Specific |
| t | Total |
| vac | Vacuum |

## SUPERSCRIPTS

| | |
|---|---|
| * | Throat |

## CALCULATIONS

### I. MAINSTAGE PERFORMANCE

#### Flow Rates

Total Propellant Flow Rate

$$W_t = W_f + W_o$$

#### Mixture Ratio

Total Propellant Mixture Ratio

$$MR = \frac{W_o}{W_f}$$

#### Vacuum Thrust

$$F_{vac} = [193.73 + 3.34\,(MR)]\,P_c + P_a\,A_e$$

where $A_e = 4643.3$ sq in.

#### Vacuum Specific Impulse

$$(I_{sp})_{vac} = \frac{F_{vac}}{W_t}$$

#### Characteristic Velocity

$$C^* = \frac{P_c A^* g}{W_t}$$

where $A^* = 117.1\ \text{in.}^2$

### II. PROPELLANT FLOW RATES

Propellant flow rates are based on engine flowmeter constants supplied by the engine manufacturer: 5.50 and 2.00 Hz per gal for the oxidizer and fuel, respectively. Propellant properties for conversion of volumetric to weight flow were obtained from Refs. 9 and 10 for hydrogen and oxygen, respectively.

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J4-1001-06, -07, -11, AND -15)

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| 11. SUPPLEMENTARY NOTES<br>Available in DDC | 12. SPONSORING MILITARY ACTIVITY<br>NASA, Marshall Space Flight Center (PM-EP-J), Huntsville, Alabama 35812 |


13. ABSTRACT Eleven firings of the Rocketdyne J-2S rocket engine were conducted in Rocket Development Test Cell (J-4) of the Engine Test Facility on August 25, 28, September 17, and October 29, 1969. These firings were accomplished at pressure altitudes ranging from 80,000 to 108,000 ft at engine start signal. The major objectives for these tests were to verify stable idle-mode operation, confirm that oxidizer injection temperatures were not excessive during transition from main-stage to post-main-stage idle-mode operation, evaluate main-stage performance, and determine the rate at which thrust chamber temperature increased during pre-main-stage idle mode. A full-face oxidizer flow injector configuration was utilized during this series of tests for the distribution of oxidizer during idle-mode operation. Brief durations (<20 sec) of stable idle-mode operation (chamber pressure oscillations <± psi) were achieved. Oxidizer injection temperatures exhibited only insignificant increases (<10°F) during transition to post-main-stage idle-mode operation. The maximum rate at which the thrust chamber temperature increased during idle-mode operation with high oxidizer (45-psia) and low fuel (27-psia) pump inlet conditions was 6°F/sec. Three firings which simulated orbital restart conditions were prematurely terminated during transition to main stage by the vibration safety cutoff system. Liquid fuel was present at the injector at dome prime when the excessive vibrations were first recorded. [This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, MSFC (PM-EP-J), Huntsville, Alabama 35812.]


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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| J-2S rocket engines | | | | | | |
| solid-propellants | | | | | | |
| performance | | | | | | |
| rocket motors | | | | | | |
| combustion efficiency | | | | | | |
| S-IVB battleship stage | | | | | | |

1. Rocket motors -- J-2S
2. " " -- Perform
3. " " -- Combustion

AFSC
Arnold AFS Tenn